PB81-192437

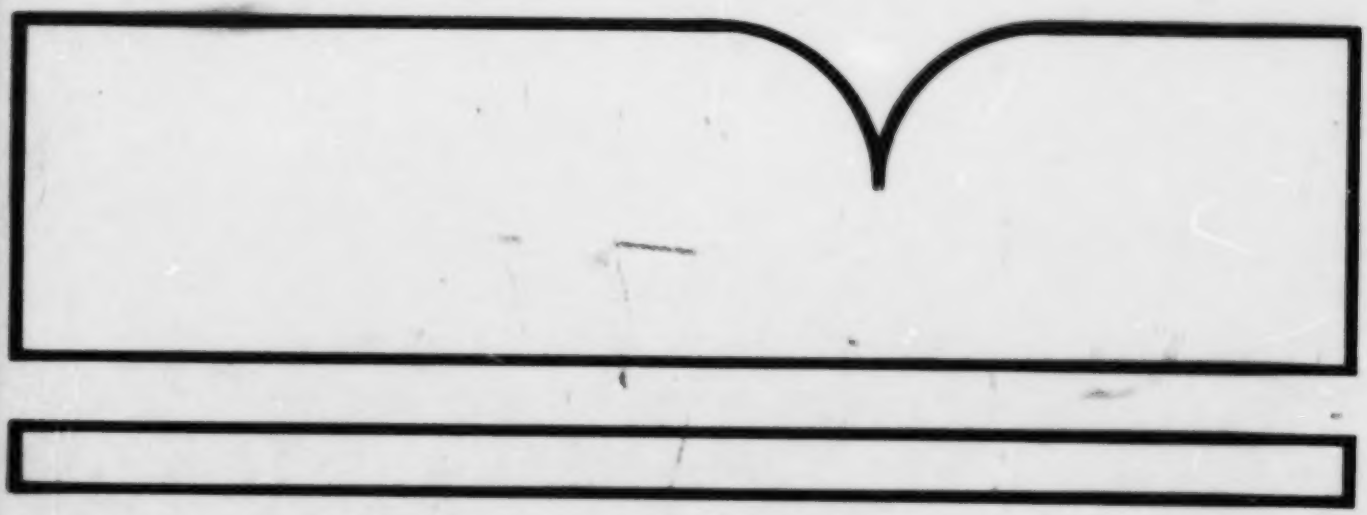
Environmental Assessment of Buccaneer Gas and Oil Field in the Northwestern Gulf of Mexico 1978-1979. Volume V

(U.S.) National Marine Fisheries Service
Galveston, TX

Prepared for

Environmental Protection Agency
Washington, DC

Dec 80



U.S. Department of Commerce
National Technical Information Service
NTIS

PB81-192437

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

NOAA FORM 25-13 (1-78)

BIBLIOGRAPHIC DATA SHEET

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

1. NOAA ACCESSION NUMBER	2.	3. RECIPIENT'S ACCESSION NUMBER
NOAA-81021704		PB81 192437

4. TITLE AND SUBTITLE Environmental Assessment of Buccaneer Gas and Oil Field in the Northwestern Gulf of Mexico, 1978-1979. Vol. V - Effects of Gas and Oil Field Structures and Effluents on Fouling Community Production and Function

5. REPORT DATE Dec 1980

6.

7. AUTHOR(S) R.L. Howard, G.S. Boland, B.J. Gallaway, and G.D. Dennis (LGL, Ecological Research Associates, Bryan, TX 77801)

8. REPORT NO. NOAA-TM-NMFS-SEFC-39

9. PERFORMING ORGANIZATION NAME AND ADDRESS
NOAA, National Marine Fisheries Service,
Galveston, TX 77550,
Southeast Fisheries Center

10. PROJECT/TASK NO.

11. CONTRACT/GRANT NO. Interagency Agreement EPA-1AG-D5-E693-EO

12. SPONSORING ORGANIZATION NAME AND ADDRESS
Same; and
Environmental Protection Agency

13. TYPE OF REPORT AND PERIOD COVERED Annual Rept. to EPA

14.

15. PUBLICATION REFERENCE
NOAA Technical Memorandum NMFS-SEFC-39, December 1980. 89 p, 16 fig, 11 tab, 24 ref.

16. ABSTRACT
Research performed during 1978-79 was designed to obtain additional information about the effects of offshore platforms and effluents on biofouling communities and to obtain information about the functioning of the system. Produced water was confirmed to be characterized by a high oxygen demand and to increase the respiratory rates of the biofouling community. Stations near the produced water discharge were observed to have significantly lower biofouling biomass than other platform supports and platforms with produced water discharges had lower microalgae biomass than control structures. Recolonization experiments confirmed previous results in showing that produced water discharge inhibits barnacle recolonization at the surface. Large barnacles (Balanus tintinnabulum) were observed to feed mainly at night with a higher level of feeding during summer than in winter. Their condition varied among seasons as a function of reproductive stage. A single recruitment of the small barnacle, Balanus amphitrite, matured in one year. Sets of the small barnacle species are typically overgrown by B. tintinnabulum in the Buccaneer Oil Field. (Author modified)

17. KEY WORDS AND DOCUMENT ANALYSIS

17A. DESCRIPTORS
*Water pollution effects, *Biota, *Fouling, Biomass, Offshore structures, Oil pollution, Gulf of Mexico, Environmental effects

17B. IDENTIFIERS/OPEN-ENDED TERMS
*Barnacles, Biofouling communities, Oil and gas fields, Balanus tintinnabulum, Tubularia crocea, Bugula neritina

17C. COSATI FIELD/GROUP
8A, 6F COWRR 05C

18. AVAILABILITY STATEMENT
Released for distribution: Elaine S. Downs

19. SECURITY CLASS (This report)	21. NO. OF PAGES
UNCLASSIFIED	90 p.
20. SECURITY CLASS (This report)	**22. PRICE**
UNCLASSIFIED	

NOAA FORM 25-13 (1-78) SUPERSEDES ALL PREVIOUS EDITIONS.

NOAA Technical Memorandum NMFS-SEFC- 39

Environmental Assessment of Buccaneer Gas and Oil Field In the Northwestern Gulf of Mexico, 1978-1979

VOL. V - EFFECTS OF GAS AND OIL FIELD STRUCTURES AND EFFLUENTS ON FOULING COMMUNITY PRODUCTION AND FUNCTION

BY
R. L. Howard, G. S. Boland B. J. Gallaway, Ph. D.,
and G. D. Dennis
LGL, Ecological Research Associates
1410 Cavitt Street, Bryan, Texas 77801

A report to the Environmental Protection Agency on work conducted under provisions of Interagency Agreement EPA-IAG-D5-E693-EO during 1978-1979.

EDITORS
William B. Jackson
Senior Advisor
Contracts & Deliverables
and
E. Peter Wilkens
Fishery Biologist

U. S. DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator

National Marine Fisheries Service
Terry L. Leitzell, Assisistant Administrator for Fisheries

This TM series is used for documentation and timely communication of preliminary results, interim reports, or similar special purpose information. Although the memos are not subject to complete formal review, editorial control, or detailed editing, they are expected to reflect sound professional work.

DISCLAIMER

This document is an Annual Report. It has been reviewed by the National Marine Fisheries Service and the National Oceanic and Atmospheric Administration and approved for printing. Such approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, NOAA or NMFS. This Report has not been formally released by the EPA. Mention of trade names or commerical products herein does not constitute endorsement or recommendation for use.

NOTICE

This document is an Annual Report. It has not been formally released by the U.S. Environmental Protection Agency and should not at this stage be construed to represent Agency policy.

This volume should be cited as follows:

Howard, R. L., G. S. Boland, B. J. Gallaway and G. D. Dennis. 1980. Effects of gas and oil field structures and effluents on fouling community production and function. Vol. V. In: Jackson, W. B. and E. P. Wilkens (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-39, 60 p. Available from NTIS, Springfield, Virginia.

Volume V - FOULING COMMUNITY

TABLE OF CONTENTS

I. Editors' Section

	Page
Project Administration	v
List of Volumes	vii
Guide to Users of the Annual Report	x
Foreword	xi
List of Reports and Publications	xiii
Published Reports	xiii
Dissertations and Theses	xvii
Publications in Press or in Preparation	xvii
Introduction	xix
Location of Study Area	xix
Operation History of Buccaneer Field	xix
Fig. 1. Location of Buccaneer Field	xx
Fig. 2. Buccaneer Field Structures	xxii
Fig. 3. Shell Oil Company's Alphanumerical Identification of Buccaneer Field Structures	xxiii

II. Principal Investigators' Section

Work Unit 2.3.8	Effects of Gas and Oil Field Structures and Effluents on Fouling Community Production and Function	xxiv

PROJECT ADMINISTRATION

NOAA

Program Manager

W. Lawrence Pugh
Oceans Program Office
Rockville, Maryland

NMFS

Contracting Officer's Technical Representative

Edward F. Klima, Ph.D.
Director
Galveston Laboratory
Southeast Fisheries Center

Project Manager

Charles W. Caillouet, Ph.D.
Chief, Environmental Research Division

Project Staff (Environmental Research Division)

William B. Jackson
Senior Advisor
Contracts and Deliverables

Gregg R. Gitschlag
Senior Advisor
Field Operations and Logistics

E. Peter H. Wilkens
Fishery Biologist

Gary M. Faw
Fishery Biologist

Robert M. Avent, Ph.D.
Oceanographer

Dennis Koi
Computer Programmer

Petronila C. Prado
Clerk Stenographer

Mary Taylor
Clerk Typist

Patsy Hunter
Clerk Typist

Susan Gray
Clerk Typist

Beatrice Richardson
Clerk Typist

Leesa Young
Biological Aide

Julie Mellen
Student Aide

Richard Devereux
Coop. Student Biologist

LIST OF VOLUMES

This Annual Report is printed in ten separate volumes:

Volume I -- SYNOPSIS/DATA MANAGEMENT

Work Unit 2.6.1 Synopsis

NMFS/SEFC Galveston Laboratory

Principal Investigators

Work Unit 2.2.3 Implement, Monitor, and Modify Data Management System

NMFS/SEFC National Fisheries Engineering Laboratory

K. Savastano
H. Holley

Volume II - SEDIMENTS AND PARTICULATES

Work Unit 2.3.2 Investigations of Surficial Sediments and Suspended Particulates at Buccaneer Field

Texas A&M University

J. Brooks, Ph.D.
E. Estes, Ph.D.
W. Huang, Ph.D.

Volume III - FISHES AND MACROCRUSTACEANS

Work Unit 2.3.5 Effect of Gas and Oil Field Structures and Effluents on Pelagic and Reef Fishes, Demersal Fishes, and Macrocrustaceans

LGL Ecological Research Associates, Inc.

B. Gallaway, Ph.D.
L. Martin

Volume IV - BACTERIA

Work Unit 2.3.7 — Bacterial Communities

University of Houston

R. Sizemore, Ph.D.
K. Olsen

Volume V - FOULING COMMUNITY

Work Unit 2.3.8 — Effects of Gas and Oil Field Structures and Effluents on Fouling Community Production and Function

LGL Ecological Research Associates, Inc.

R. Howard
G. Boland
B. Gallaway, Ph.D.
G. Dennis

Volume VI - CURRENTS AND HYDRCGRAPHY

Work Unit 2.3.9 — Currents and Hydrography of the Buccaneer Field and Adjacent Waters

Hazleton Environmental Sciences Corporation

L. Danek, Ph.D.
M. Tomlinson

Volume VII - HYDROCARBONS

Work Unit 2.4.1 — Hydrocarbons, Biocides, and Sulfur

University of Houston

B. Middleditch, Ph.D.
D. West

Volume VIII - TRACE METALS

Work Unit 2.4.2 Trace Metals

Southwest Research Institute

J. Tillery

Volume IX - FATE AND EFFECTS MODELING

Work Unit 2.5.1 Sources, Fate and Effects Modeling

Science Applications, Inc.

K. Fucik, Ph.D.
I. Show, Ph.D.

Volume X - HYDRODYNAMIC MODELING

Work Unit 2.5.2 Hydrodynamic Modeling

Environmental Research and Technology, Inc.

G. Smedes, Ph.D.
J. Calman
J. Beebe

GUIDE TO USERS OF THE ANNUAL REPORT

Volume I (SYNOPSIS/DATA MANAGEMENT) of the Annual Report is designed to be used as a briefing document and as a key to more detailed scientific and technical information contained in Volumes II through X. Objectives, methods and results for each work unit are summarized in greatly abbreviated form within Volume I to facilitate dissemination of information. Thus, Volume I can be used alone or as a reference to companion Volumes II through X. Complete citations for literature cited in Volume I can be found in the Volumes II through X in which the detailed work unit reports are presented.

It is hoped that such an approach to environmental impact information dissemination will make the Annual Report a more useful and widely read document.

FOREWORD

Increased petroleum development of the outer continental shelf (OCS) of the United States is anticipated as the U.S. attempts to reduce its dependency on foreign petroleum supplies. To obtain information concerning the environmental consequences of such development, the Federal Government has supported major research efforts on the OCS to document environmental conditions before, during, and after oil and gas exploration, production, and transmission. Among these efforts is the Environmental Assessment of Buccaneer Gas and Oil Field in the Northwestern Gulf of Mexico, a project funded by the Environmental Protection Agency (EPA) through interagency agreement with the National Oceanic and Atomospheric Administration (NOAA) and managed by the National Marine Fisheries Service (NMFS), Southeast Fisheries Center (SEFC), Galveston Laboratory, in Galveston, Texas. Initiated in the autumn of 1975, the study is now in its last year. Its major products have been annual reports disseminated by the National Technical Information Service, data files archived and disseminated by NOAA's Environmental Data and Information Service, and research papers written by participating investigators and published in scientific or technical journals. Results have also been made available through EPA/NOAA/NMFS project reviews and workshops attended by project participants, and various governmental (Federal and State), private, and public user groups. The final products will be milestone reports summarizing the findings of the major investigative components of the study.

Objectives of the project are (1) to identify and document the types and extent of biological, chemical and physical alterations of the marine ecosystem associated with Buccaneer Gas and Oil Field, (2) to determine specific pollutants, their quantity and effects, and (3) to develop the capability to describe and predict fate and effects of Buccaneer Gas and Oil Field contaminants. The project uses historical and new data and includes investigations both in the field and in the laboratory. A brief Pilot Study was conducted in the autumn and winter of 1975-76, followed by an extensive biological/chemical/physical survey in 1976-77 comparing the Buccaneer Gas and Oil Field area with adjacent undeveloped or control areas. In 1977-78, investigations were intensified within Buccaneer Gas and Oil Field, comparing conditions around production platforms, which release various effluents including produced brine, with those around satellite structures (well jackets) which release no effluents. In 1978-79, studies around Buccaneer Gas and Oil Field structures focused

on (1) concentrations and effects of pollutants in major components of the marine ecosystem, including seawater, surficial sediments, suspended particulate matter, fouling community, bacterial community, and fishes and macro-crustaceans, (2) effects of circulation dynamics and hydrography on distribution of pollutants, and (3) mathematical modeling to describe and predict sources, fate and effects of pollutants. The final year, 1979-80, of study is continuing to focus on items (1) and (2) and on preparation of the milestone reports which will represent the final products of this study.

This project has provided a unique opportunity for a multi-year investigation of effects of chronic, low-level contamination of a marine ecosystem associated with gas and oil production in a long-established field. In many respects, it represents a pioneering effort. It has been made possible through the cooporation of government agencies, Shell Oil Company (which owns and operates the field) and various contractors including universities and private companies. It is anticipated that the results of this project will impact in a significant way on future decisions regarding operations of gas and oil fields on the OCS.

Charles W. Caillouet, Project Manager
Chief, Environmental Research Division
and
William B. Jackson and E. Peter Wilkens,
Editors

LIST OF REPORTS AND PUBLICATIONS

Published Reports

Brooks, J. M., E. L. Estes and W. Huang. 1980. Investigations of surficial sediments and suspended particulates at Buccaneer field. Vol. II. In: Jackson, W. B. and E. P. Wilkens (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-36, 261 p. Available from: NTIS, Springfield, Virginia.

Danek, L. J. and M. S. Tomlinson. 1980. Currents and hydrography of the Buccaneer field and adjacent waters. Vol. VI. In: Jackson, W. B. and E. P. Wilkens, (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-40, 33 p. Available from: NTIS, Springfield, Virginia.

Finucane, J. H. 1977. Ichthyoplankton of the Buccaneer oil field off Galveston, Texas. Paper presented at the Fourth Biennial International Estuarine Research Conference, Mt. Pocono, Pa. (abstract published in proceedings).

Fucik, K. and I. T. Show, Jr. 1980. Sources, fate and effects modeling. Vol. IX. In: Jackson, W. B. and E. P. Wilkens (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-43, 105 p. Available from: NTIS, Springfield, Virginia.

Gallaway, B. J., R. Howard, K. Green and L. Martin. 1976. A study plan for the Buccaneer oil field assessment program. A report to NMFS from LGL Limited-U.S., Inc., Bryan, Texas, 69 pp.

Gallaway, B. J. and L. R. Martin. 1980. Effect of gas and oil field structures and effluents on pelagic and reef fishes, and demersal fishes and macrocrustaceans. Vol. III. In: Jackson, W. B. and E. P. Wilkens (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-37, 49 p. Available from: NTIS, Springfield, Virginia.

Harper, D. E., Jr., R. J. Scrudato and C. S. Giam. 1976. A preliminary environmental assessment of the Buccaneer oil/gas field (pilot study of the Buccaneer oil field (benthos and sediments).

A final report from Texas A&M University to the National Marine Fisheries Service, Galveston, Texas (Contract No. 03-6-042-35110), 63 pp.

Hollaway, S. J., G. M. Faw, R. K. Sizemore. 1980. The bacterial community composition of an active oil field in the northwestern Gulf of Mexico. Mar. Poll. Bull. 11:153-156.

Howard, R. L, G. S. Boland, B. J. Gallaway and G. D. Dennis. 1980. Effects of gas and oil field structures and effluents on fouling community production and function. Vol. V. In: Jackson, W. B. and E. P. Wilkens (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-39, 60 p. Available from: NTIS, Springfield, Virginia.

Jackson, W. B. (Editor). 1977. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1976-1977. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO, 759 pp. Available from: NTIS, Springfield, Virginia, Accession No. PB283890.

Jackson, W. B. (Editor). 1979. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1977-1978. Volume I: Synopsis. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO. 62 pp. Available from: NTIS, Springfield, Virginia, Accession No. PB301339/AS.

Jackson, W. B. (Editor). 1979. Environmental assessement of an active oil field in the northwestern Gulf of Mexico, 1977-1978. Volume III: Chemical and physical investigations. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO. 722 pp. Available from: NTIS, Springfield, Virginia, Accession No. PB80107899.

Jackson, W. B. (Editor). 1979. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1977-1978. Volume II: Data management and biological investigations. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO, 799 pp. Available from: NTIS, Springfield, Virginia, Accession No. PB80165970.

Jackson W. B. and E. P. Wilkens. (Editors). 1980. Synopsis. Vol. I. In: Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-35, p. Available from: NTIS, Springfield, Virginia.

Jackson, W. B., K. N. Baxter and C. W. Caillouet. 1978. Environmental assessment of the Buccaneer oil and gas field off Galveston, Texas: An overview. Proceedings of the Offshore Technology Conference, May, 1978, Houston, Texas, OTC 3081:277-284.

Jackson, W. B., K. N. Baxter, and C. W. Caillouet. 1979. Environmental assessment of an offshore oil field. Ecolibrium 8(1): 7-9.

McCall, J. O. and R. K. Sizemore. 1979. Description of a bacteriocinogenic plasmid in Beneckea harveyi. Appl. Environ. Microbiol. 38(5):974-979.

McKinney, L. 1979. Liljeborgiid amphiopods from the Gulf of Mexico and Caribbean Sea. Bull. Mar. Sci. 29(2):140-154.

Middleditch, B. S. and B. Basile. 1976. Deuteriated analogs as internal standards for the quantitation of environmental alkanes by gas chromatography. Analyt. Letters 9(11):1031-1034.

Middleditch, B. S. and B. Basile. 1979. Sulfur-34 as an internal standard for quantitation of environmental sulfur by combined gas chromatography-mass spectometry. Analyt. Letters 12(A7):777-781.

Middleditch, B. S., B. Basile and E. S. Chang. 1977. Environmental effects of offshore oil production: alkanes in the region of the Buccaneer oilfield. J. Chromatography 142(1977):777-785.

Middleditch, B. S., B. Basile and E. S. Chang. 1978. Alkanes in surficial sediments from the region of the Buccaneer oilfield. J. Chromatography 158:449-463.

Middleditch, B. S., B. Basile and E. S. Chang. 1978. Discharge of alkanes during offshore oil production in the Buccaneer oilfield. Bull. Environ. Contam. Toxicol. 20:59-65.

Middleditch, B. S., B. Basile and E. S. Chang. 1979. Alkanes in seawater in the vicinity of the Buccaneer oilfield. Bull. Environ. Contam. Toxicol. 21:413-420.

Middleditch, B. S., E. S. Chang and B. Basile. 1979. Alkanes in barnacles (Balanus tintinnabulum) from the Buccaneer oilfield. Bull. Environ. Contam. Toxicol. 23:6-12.

Middleditch, B. S., E. S. Chang and B. Basile. 1979. Alkanes in plankton from the Buccaneer oilfield. Bull. Environ. Contam. Toxicol. 21:421-427.

Middleditch, B. S., E. S. Chang, B. Basile, and S. R. Missler. 1979. Alkanes in fish from the Buccaneer oilfield. Bull. Environ. Contam. Toxicol. 22:249-257.

Middleditch, B. S. and D. L. West. 1979. Bicyclohexyl interference in the quantitation of environmental alkanes by gas chromatography. Analyt. Letters 12(A12):1279-1284.

Middleditch, B. S. and D. L. West. 1980. Hydrocarbons, biocides, and sulfur. Vol. VII. In: Jackson, W. B. and E. P. Wilkens, (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-41, p. Available from: NTIS, Springfield, Virginia.

National Marine Fisheries Service. 1977. Environmental assessment of an active oil field in the northwestern Gulf of Mexico. A report of NMFS/LGL Workshop I, 1977-1978. NMFS Galveston Laboratory, Southeast Fisheries Center, NOAA, USDOC. Project Number EPA-IAG-D5-E693-EO.

Savastano, K. and H. Holley. 1980. Implement, monitor, and modify data management system. Vol. I. In: Jackson, W. B. and E. P. Wilkens (eds.). Environmental asessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-35. p. Available from: NTIS, Springfield, Virginia.

Show, I. T., Jr. 1979. An application of compartmental models to mesoscale marine ecosystems, pages 73-97. In: J. H. Matis, B. C. Patten, and G. C. White (eds.). Compartmental analysis of ecosystem models. International Co-operative Publishing House, Fairland, Maryland, U.S.A.

Sizemore, R. K. and K. Olsen. 1980. Bacterial communities. Vol. IV. In: Jackson, W. B. and E. P. Wilkens (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-38, 32 p. Available from: NTIS, Springfield, Virginia.

Smedes, G., J. Calman and J. Beebe. 1980. Hydrodynamic modeling. Vol. X. In: Jackson, W. B. and E. P. Wilkens (eds.). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-44, 57 p. Available from: NTIS, Springfield, Virginia.

Tillery, J. B. 1980. Trace metals. Vol. VIII. In: Jackson, W. B. and E. P. Wilkens, (eds.). Environmental assessment of Buccaneer

gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-42, 93 p. Available from: NTIS, Springfield, Virginia.

Wheeler, R. B., R. R. Schwarzer and J. B. Anderson. 1978. Assessment of environmental impact of offshore production in the Buccaneer oil field: sedimentologic and geochemical results. Proceedings of the Offshore Technology Conference, May 1978, Houston, Texas OTC 3082:285-290.

Dissertations and Theses

Basile, B. 1978. Environmental effects of offshore oil production. Ph.D. Dissertation, University of Houston, Houston, Texas.

Boland, G. S. 1980. Morphological parameters of the barnacle, Balanus tintinnabulum antillensis, as indicators of physiological and environmental conditions. M. S. Thesis, Texas A&M University, College Station, Texas.

Chang, E. S. 1978. Sterols in the marine food web. M.S. Thesis, University of Houston, Houston, Texas.

McCall, J. O. 1979. Isolation and characterization of a bacteriocinogenic strain of the bioluminescent marine bacterium Beneckea harveyi. M.S. Thesis, University of Houston, Houston, Texas.

West, D. L. 1979. Hydrocarbons, sulfur and acrolein in the marine ecosystem associated with offshore oil production. M.S. Thesis, University of Houston, Houston, Texas.

Wheeler, R. B. 1979. Environmental trace metal geochemistry of the Buccaneer oil and gas field. M.S. Thesis, Rice University, Houston, Texas. 176 pp.

Publications in Press or in Preparation

Anderson, J. B., R. R. Schwarzer, B. S. Middleditch, and B. Basile. Trace metal and hydrocarbon distribution in the region of the Buccaneer oil field. M.S. in preparation.

Devereux, R. and R. K. Sizemore. Incidence of degradative plasmids in hydrocarbon-utilizing bacteria. M.S. submitted to Developements in Industrial Microbiology.

Hada, H. S. and R. K. Sizemore. A survey of the incidence of plasmids in marine Vibrio spp. M.S. submitted to Appl. Environ. Microbiol.

McKinney, L. The genus Photis from the Texas coast with a description of a new species, Photis melanicus. Contrib. Mar. Sci. (in press).

Middleditch, B. S. and B. Basile. 1980. Alkanes in shrimp from the Buccaneer oilfield. Bull. Environ. Contam. Toxicol. (in press).

Middleditch, B. S. and B. Basile. 1980. Alkanes in benthic organisms from the Buccaneer oilfield. Bull. Environ. Contam. Toxicol. (in press).

Middleditch, B. S. and B. Basile. 1980. Discharge of elemental sulfur and its distribution in the region of the Buccaneer oilfield. J. Chromatog. (in press).

Olsen, K. D. and R. K. Sizemore. Effects of an established offshore oil platform on the autochthonous bacteria community. M. S. submitted to Developments in Industrial Microbiology.

Rose, C. D. and T. J. Ward. Principles of aquatic hazard evaluation as applied to ocean-disposed wastes. M.S. in preparation; intended for publication as a report for Amer. Soc. Testing. Materials.

Wheeler, R. B. 1980. Environmental trace metal geochemistry of the Buccaneer oil and gas field. Environ. Geol. (in press).

INTRODUCTION

Location of Study Area

The area selected for study is the operational Buccaneer Gas and Oil Field located approximately 49.6 kilometers (26.8 nautical miles) south southeast of the Galveston Sea Buoy off Galveston, Texas (Figure 1). This field was selected in 1975 as the study area because: (a) the field had been in production for about 15 years, which time had allowed full development of the associated marine communities; (b) it was isolated from other fields which facilitated the selection of an unaltered area (for comparison) within a reasonable distance of the field; (c) it produced both gas and oil that represented sources of pollutants from marine petroleum extraction; (d) its location simplified logistics and reduced the cost of the research; and (e) the Texas offshore area had not been fully developed for gas and oil production but was expected to experience accelerated exploitation in the future.

Operation History of Buccaneer Field

Buccaneer Field was developed by Shell Oil Company in four offshore blocks leased in 1960 and 1968 as follows:

Year	Lease Number	Block Number	Acreage	Hectares
1960	G0709	288	2,790	1,129
1960	G0713	295	4,770	1,930
1960	G0714	296	4,501	1,821
1968	G1783	289	2,610	1,056

In development of the field, 17 structures were built; two are production platforms, two are quarters platforms, and 13 are satellite structures surrounding well jackets. Initial exploratory drilling began about mid-summer of 1960 with mobile drilling rigs. When (as the result of the exploratory drilling) proper locations for platforms were selected, the permanent production platforms were constructed.

There have been no reports of major oil spills from this field. There have been some reported losses of oil due to occasional mechanical failure of various pieces of equipment. The largest

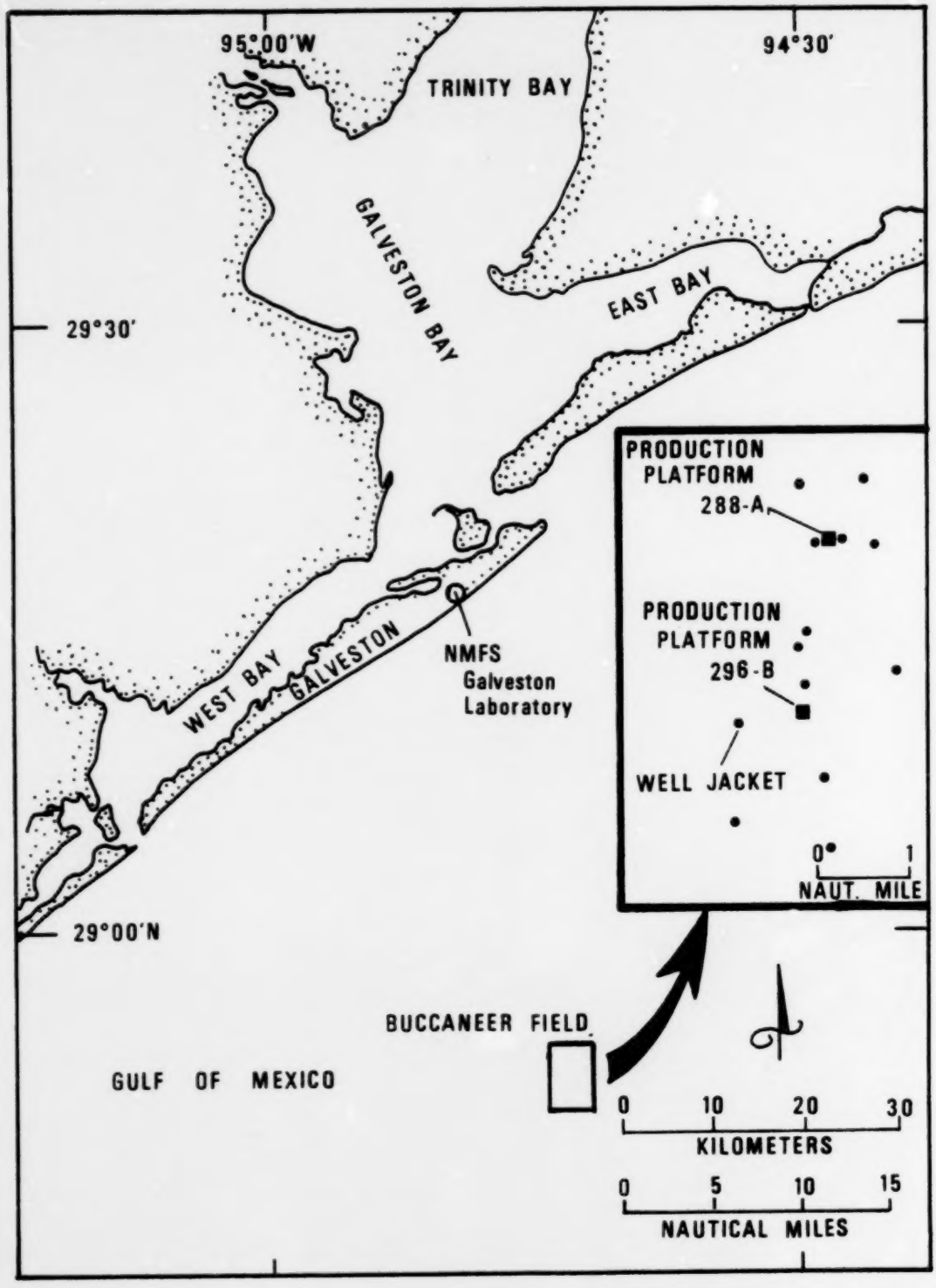


FIGURE 1. LOCATION OF BUCCANEER FIELD

reported spill was three barrels in 1973. The reported oil spill chronology and quantity for Buccaneer Field is as follows:

Date	Source	Amount	
		Barrels	Liters
September 1973	Platform 296-B	0.5	79
November 1973	Unknown	3.0	477
July 1974	Platform 296-B	0.5	79
August 1974	Platform 296-B	1.7	265
September 1975	Platform 288-A	0.2-0.4	38-56
Totals		5.9-6.1	938-956

Buccaneer Field first began operations with the production of oil. Later, when significant quantities of gas were found, the field began producing both oil and gas and has continued to do so to date.

The production platforms and satellites (well jackets) are connected by a number of pipelines with a 50.8 centimeters (20-inch) diameter main pipeline connecting the field to shore. All of the pipelines that are 25.4 centimeters (10 inches) or greater in diameter are buried. The Blue Dolphin Pipeline Company was granted a pipeline permit (No. G1381, Blocks 288 and 296) in 1965 and has operated the pipeline since its construction.

Buccaneer Field occupies a limited area (about 59.3 km^2; 22.9 sq. statute miles) leased in the northwestern Gulf of Mexico. Four types of structures are located in Buccaneer Field: production platforms, quarters platforms, satellites (well jackets), and flare stacks. These are shown in Figure 2, which is an oblique aerial photograph of production platform 288-A and vicinity within Buccaneer Field. A map of Buccaneer Field, (Figure 3) depicts the locations of platforms and satellites within the field.

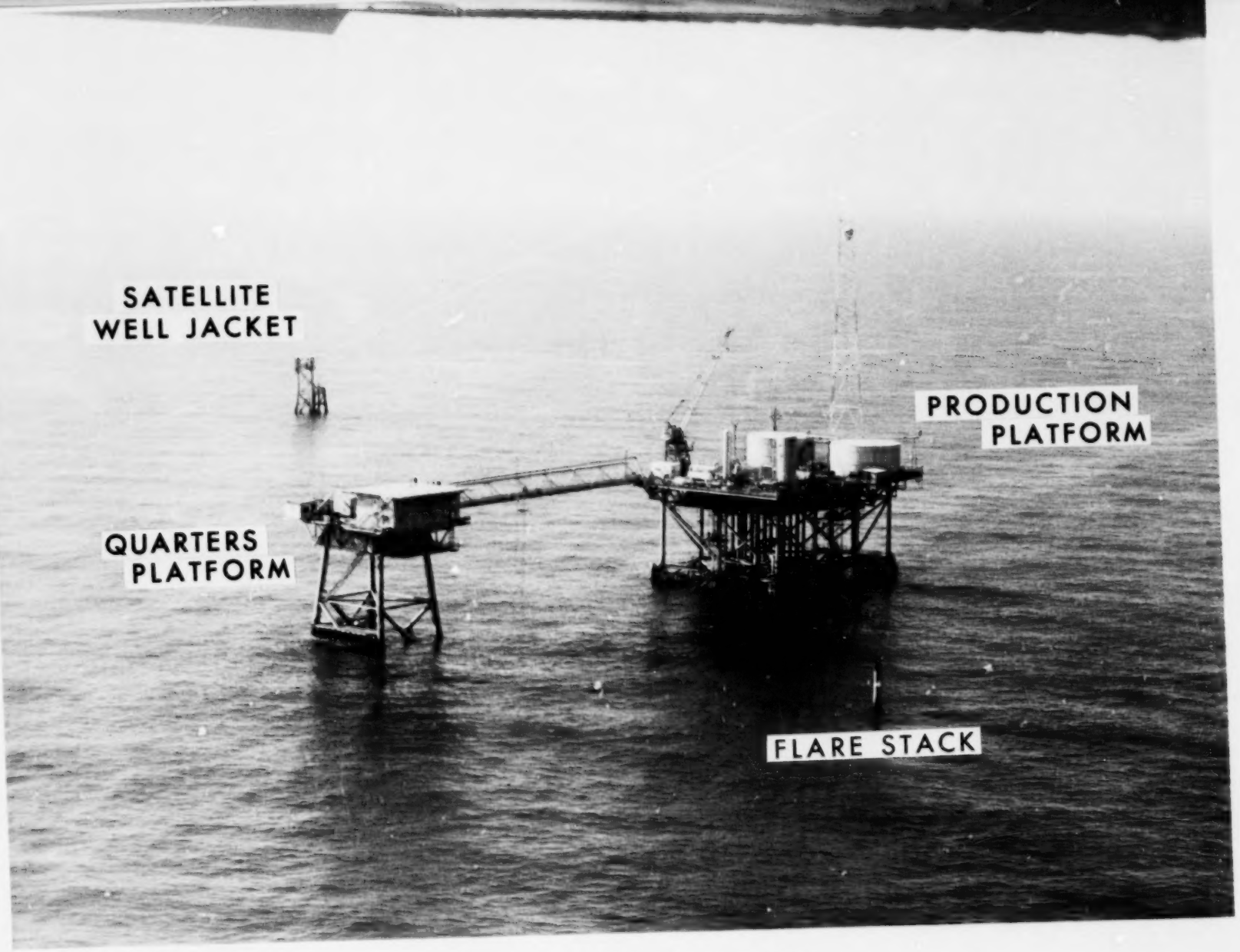


FIGURE 2. BUCCANEER FIELD STRUCTURES

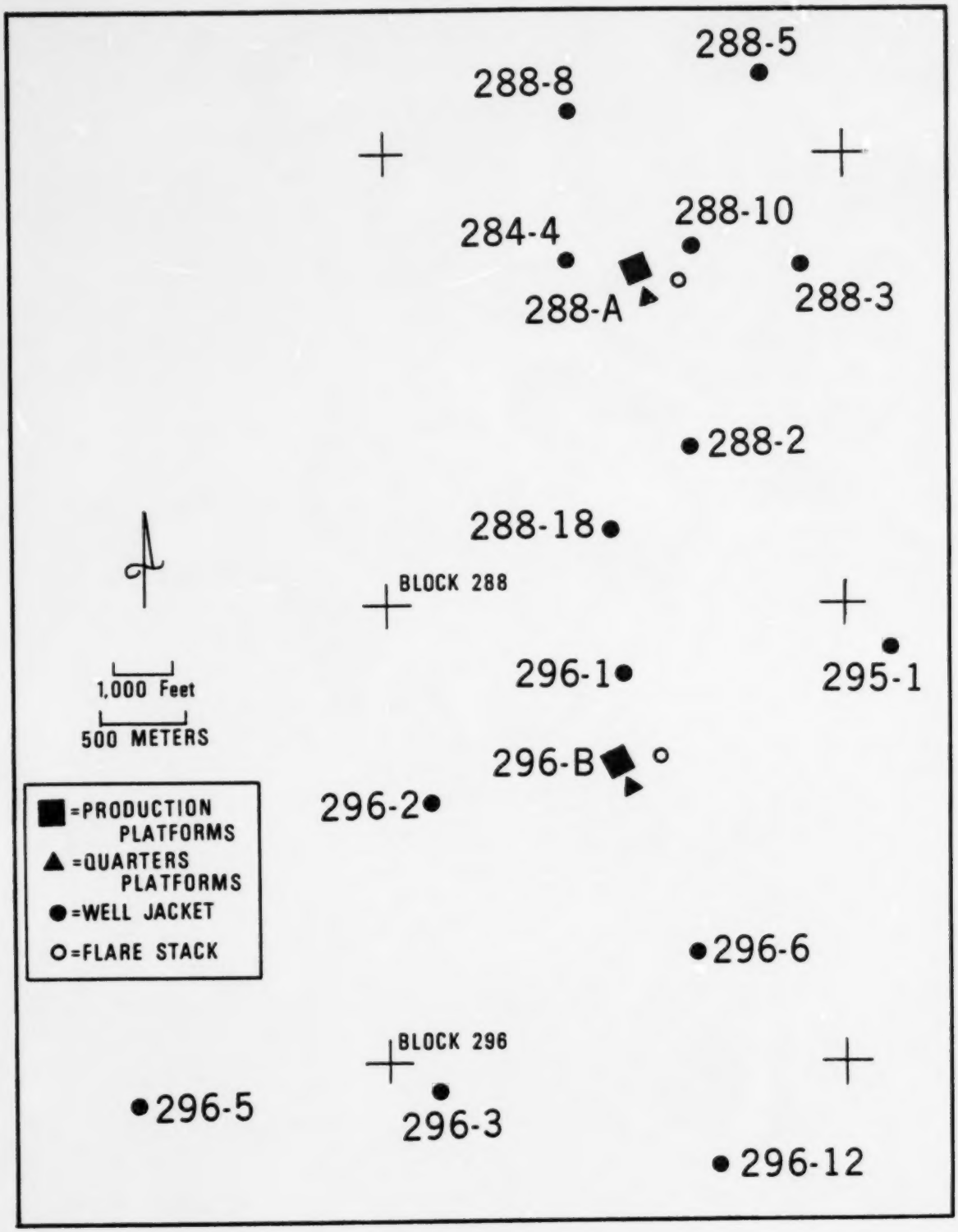


FIGURE 3. SHELL OIL COMPANY'S ALPHANUMERICAL IDENTIFICATION OF BUCCANEER GAS AND OIL FIELD STRUCTURES

WORK UNIT 2.3.8 - EFFECTS OF GAS AND OIL FIELD STRUCTURES AND EFFLUENTS ON FOULING COMMUNITY PRODUCTION AND FUNCTION

LGL Ecological Research Associates, Inc.

R. L. Howard
G. S. Boland
B. J. Gallaway, Ph.D.
G. D. Dennis

TABLE OF CONTENTS

	Page
INTRODUCTION	2.3.8- 1
METHODS AND MATERIALS	2.3.8- 3
Effluent Discharge and Related Sampling	2.3.8- 4
Respirometry	2.3.8- 4
Effects Based upon Harvest Sampling	2.3.8- 5
Effects Based upon Recolonization Sampling	2.3.8-10
Condition of *Balanus tintinnabulum*	2.3.8-13
Feeding of *B. tintinnabulum*	2.3.8-14
Production of the Small Barnacle, *B. amphitrite*	2.3.8-15
Production of the Hydroid, *Tubularia crocea*	2.3.8-15
Production of the Bryozoan, *Bugula neritina*	2.3.8-16
RESULTS AND DISCUSSION	2.3.8-16
Effluent Discharge	2.3.8-17
Respirometry	2.3.8-17
Harvest Sampling	2.3.8-20
Total Biomass	2.3.8-20
Fouling Mat Biomass	2.3.8-22
Numbers of *B. tintinnabulum*	2.3.8-23
Cryptic Macrofauna	2.3.8-28
Flora	2.3.8-39
Pipeline Biomass	2.3.8-42
Recolonization	2.3.8-42
Condition of *B. tintinnabulum*	2.3.8-48
Toxicity Observations	2.3.8-49
Feeding of *B. tintinnabulum*	2.3.8-50
Production of the Small Barnacle, *B. amphitrite*	2.3.8-52
Production of the Hydroid, *Tubularia crocea*	2.3.8-52
Production of the Bryozoan, *Bugula neritina*	2.3.8-55
CONCLUSIONS AND SIGNIFICANT FINDINGS	2.3.8-56
LITERATURE CITED	2.3.8-58

LIST OF TABLES

Table		Page
1.	Table of coefficients for orthogonal contrasts used to compare data from biofouling collections taken during summer 1978	2.3.8- 9
2.	Results of ANOVA performed on abundance data for live and dead *Balanus tintinnabulum* on BOF structures during summer 1979	2.3.8-24
3.	Mean densities of cryptic organisms during summer 1978 and winter 1979	2.3.8-29
4.	Results of ANOVA performed on summer and winter pistol shrimp abundance data for Buccaneer Oil Field 1978-1979 ..	2.3.8-31
5.	Results of ANOVA performed on summer and winter stone crab abundance data for the Buccaneer Oil Field, 1978-1979	2.3.8-33
6.	Results of ANOVA performed on summer and winter brittle star abundance data for the Buccaneer Oil Field, 1978-1979	2.3.8-38
7.	Algae biomass by structure and depth in the Buccaneer Oil Field, summer 1978-1979	2.3.8-40
8.	Algae biomass by structure and depth in the Buccaneer Oil Field, winter 1978-1979	2.3.8-41
9.	Results of ANOVA performed on total biomass data for surface recolonization samples collected seasonally in the Buccaneer Oil Field, 1978-1979	2.3.8-44
10.	Results of ANOVA performed on total biomass data for recolonization samples taken seasonally at the surface, 3-, 5- and 8-m deep stations on Production Platform 296B and Satellite 288-5, 1978-1979	2.3.8-45
11.	Small barnacle production measurements	2.3.8-54

LIST OF FIGURES

Figure		Page
1.	Locations of sampling sites for measuring areal biomass variations during summer and winter	2.3.8- 6
2.	Diagrammatic representation of scraping templates	2.3.8- 7
3.	Map showing relative locations of oil field structures sampled for recolonization, *B. tintinnabulum* condition, small barnacle production, barnacle feeding observations, and hydroid and bryozoan growth during winter	2.3.8-11
4.	Discharge rates of produced water from Production Platform 296B, 1978-1979	2.3.8-18
5.	Distributional patterns of biofouling community total wet weight among BOF structures, summer 1978	2.3.8-21
6.	Distributional patterns of the density of live *B. tintinnabulum* among BOF structures, summer 1978	2.3.8-25
7.	Distributional patterns of the density of dead *B. tintinnabulum* among BOF structures, summer 1978	2.3.8-26
8.	Pistol shrimp length frequency histograms for stations 288-5, 288P, 296P, and 296F, summer 1978 and winter 1979	2.3.8-30
9.	Distributional patterns of the pistol shrimp among BOF structures, 1978-1979	2.3.8-34
10.	Distributional patterns of the stone crab among BOF structures, summer 1978	2.3.8-35
11.	Relationship of stone crab density to pistol shrimp density observed during summer 1978	2.3.8-36
12.	Distributional patterns of the brittle star among BOF structures, summer 1978	2.3.8-37
13.	Schedule for recolonization experiments performed in the Buccaneer Oil Field, 1978-1979	2.3.8-43
14.	Recolonization biomass produced on BOF structures, 1978-1979	2.3.8-47
15.	Diurnal activity of *Balanus tintinnabulum*, 18-19 August 1978	2.3.8-51
16.	Artistic representation of the spring decline of a hydroid colony at 8-m depth on 296Q	2.3.8-53

ABSTRACT

Research performed during 1978-1979 as part of Work Unit 2.3.8 was designed to (1) obtain additional information about the effects of offshore platforms and effluents on biofouling communities and (2) to obtain information about the functioning of the system. Some 5.08 x 10^5 bbl of produced water were estimated to have been discharged from Production Platform 296B during 1978-1979. Produced water was confirmed to be characterized by a high oxygen demand and to increase the respiratory rates of the biofouling community.

Stations near the produced water discharge were observed to have significantly lower biofouling biomass than other platform supports and platforms with produced water discharges had lower macroalgae biomass than control structures. Recolonization experiments confirmed previous results in showing that produced water discharge inhibits barnacle recolonization at the surface.

Large barnacles (*Balanus tintinnabulum*) were observed to feed mainly at night with a higher level of feeding during summer than in winter. Their condition varied among seasons as a function of reproductive stage. A single recruitment of the small barnacle, *Balanus amphitrite*, matured in one year and the observed production rate was 9.3 g/m^2/d (where d represents a 24-h period). Sets of the small barnacle species are typically overgrown by *B. tintinnabulum* in the Buccaneer Oil Field (BOF).

The biomass production of an average stalk of the hydroid *Tubularia crocea* during winter was measured at 0.00016 g/d (regrowth) and 0.00042 g/d (undamaged). Bryozoan (*Bugula neritina*) production during winter was 0.24 mg/cm^2/d. Both values are representative of net production.

EFFECTS OF GAS AND OIL FIELD STRUCTURES AND EFFLUENTS ON FOULING COMMUNITY PRODUCTION AND FUNCTION

INTRODUCTION

The proliferation of offshore oil and gas structures on the continental shelf of the northwestern Gulf of Mexico has resulted in renewed interest in marine organisms which colonize hard substrates (biofouling or fouling organisms). Initially, this interest was attributable to their apparent role in the transformation of sterile structures into reefs, artificial only to the extent that the base substrate is a man-made alloy as opposed to a naturally-occurring material. Results of studies describing the zonation and composition of organisms growing on oil platforms in the northern Gulf have been provided by Gunter and Geyer (1955), Pequegnat and Pequegnat (1968), George and Thomas (1974), Humm (undated), Fotheringham (1977), Gallaway et al. (1979a) and Gallaway et al. (1979b). The latter three papers are significant to this program from a community structure point-of-view in that they demonstrate that biofouling communities on Platforms in the Buccaneer Oil Field (BOF) differ significantly from those in the equivalent coastal zone offshore Louisiana. The primary difference is that, although both community types are dominated in terms of biomass by barnacles, the dominant species on BOF structures is the large Mediterranean barnacle *Balanus tintinnabulum*, whereas small acorn barnacles (primarily the *Balanus amphitrite* complex) dominate Louisiana platforms. The difference in the degree of relief provided by the two forms results in the development of an apparently more diverse and abundant macrocryptic fauna (e.g., blennies, Blennidae) on BOF structures (high relief) than is typical for platforms in the same coastal zone offshore Louisiana (low relief).

Heretofore, the biofouling community has been generally assumed of great trophic importance to the markedly large concentrations of fishes characteristic at coastal platforms. Results provided by Gallaway et al. (1979a) and Gallaway and Martin (1980) show that while this is probably true for most macrocryptic species and typical, nearshore reef species (e.g., triggerfish, Balistidae; sheepshead, Sparidae; damselfishes, Pomacentridae; butterfly and angelfishes, Chaetodontidae; and chubs, Kyphosidae), it does not appear to be the case for the abundant species which comprise most of the fish biomass at nearshore platforms (e.g., spadefish, Ephippidae; some grunts, Pomadasyidae; bluefish, Pomatomidae; and red snapper, Lutjanidae). Thus, the direct trophic importance of the biofouling community to the overall fish community residing at coastal platforms may not be as important a factor as generally assumed. The biofouling community is undoubtably important, however, to the colorful, reef-fish and cryptic assemblages from both a trophic and habitat view. Some of these trophically-dependent species (e.g., sheepshead) are of recreational importance to man as food and game fishes.

As described by Gallaway et al. (1976), production of oil and gas in the BOF has been (and is) a relatively clean operation. The only effluents of consequence in the field are produced water from production platforms and treated sewage from the treatment plant on quarters platforms. In the context of an oil and gas production operation, produced water is the water contained in the gas-oil-water mixtures being exploited. This by-product is separated from the oil and gas and discharged overboard as described by Gallaway et al. (1976). This effluent contains low levels of contaminants and, although of low volume (estimated at 95 m^3/day or ≈ 600 bbl/day during 1976-1978), represents one of the two major sources of contaminants being discharged from BOF platforms to the environment.

Gallaway et al. (1979a, 1979b) provide the only data describing the *in situ* effects of produced water on biofouling communities of oil platforms in the northwestern Gulf of Mexico. In the former study, produced water was documented to have detrimental effects in at least the immediate vicinity of the discharge. Evidence of adverse effects included low biomass and density of most fouling organisms, low survival rates of barnacles, low rates of production and recolonization and marked alteration of community structure. The latter study documented similar results for platforms in the coastal zone offshore Louisiana.

That the produced water had any measurable effect was both surprising and disturbing because of the characteristic low level of contaminants in the stream and the rapid dilution of the effluent. Although Mackin (1971) had previously reported that produced water had detrimental effects on the bottom fauna in shallow Texas bays and estuaries, he (1973) later reported that in deep or large bodies of water, dilution of the "brine" was almost instantaneous. Koons et al. (1976) had reported that they believed that the toxic components of produced water were in such low concentrations, that natural forces such as dilution and evaporation and chemical and biological reactions rapidly reduced the concentrations of the toxic components to levels not harmful to marine organisms.

Given the above, the goals of the 1978-1979 research project dealing with the biofouling community were to (1) estimate the amount of produced water being discharged, (2) define the spatial extent that direct effects of the produced water on the biofouling community could be detected and (3) gather information contributing to an understanding of the functionings of the biofouling community in the BOF ecosystem. We also collected and provided to other investigators samples of produced water, seawater, surficial sediments, suspended particulate matter and biota for analyses and characterization in terms of composition and levels of contaminants, principally biocides, hydrocarbons and trace metals. Concurrent with our biological field investigations, bioassays and microbial and oceanographic process studies were also being performed. Thus, the goals of the overall 1978-1979 BOF research program were to determine (1) concentrations and effects of contaminants on major ecosystem components, (2)effects of circulation dynamics and hydrography on contaminant distribution

in the environment and (3) to use mathematical modeling to describe and predict sources, fate and effects of pollutants. Results of this and previous year's research in the BOF are intended to collectively contribute to an integrated assessment of the significance of the observed effects of contaminants associated with a producing oil and gas field on the environment and ecosystem of the continental shelf. Results of this year's biofouling research was specifically designed to further delineate effects, and to fill data gaps necessary to describe the functionings of the community. Results reported herein may thus appear somewhat fragmented and incomplete with respect to an overall assessment. A history of the development of the BOF and descriptions of the study area can be found in Gallaway et al. (1976), Gallaway and Margraf (1978), or in any of the 1976-1978 NOAA annual reports to EPA (Jackson 1977, 1979a,b,c). For a quantitative description of the BOF fouling community in terms of structure and seasonal abundance, the reader is referred to Gallaway et al. (1979a); and, for a characterization of the role of the fouling community in trophic dynamics, to Gallaway and Margraf (1978). The concepts presented in those reports are further evolving based upon ongoing research, all of which will be comprehensively described and evaluated in the Final Milestone report.

METHODS AND MATERIALS

Sampling during this year's program (1978-1979) specifically designed to measure direct effects involved (1) seasonal measurement of produced water discharge rates at production platform 296B with samples of the effluent and receiving environment taken synoptically for chemical characterization; (2) seasonal respirometry experiments designed to evaluate the effects of the produced water on oxygen-demand characteristics of the biofouling community; (3) spatial extent of measurable effects of the produced water on biofouling community biomass and abundance; (4) confirmation of the effects of produced water on recolonization of platform substrate by the biofouling community; and (5) effects of seasons and the produced water on the condition of the primary habitat former, *B. tintinnabulum*. Results from all of the above contribute towards, and were necessary for, the development of our understanding of the functioning of the biofouling community in the BOF.

To complement the above, additional experiments were performed to describe other aspects of community function which were believed to be necessary for the eventual impact assessment. These related to (1) obtaining indices of feeding and assimilation capabilities of *B. tintinnabulum*; (2) the production and fate of small barnacles (why does *B. tintinnabulum* dominate?), and (3) production aspects of certain hydroids and branching bryozoans. These forms are seasonally abundant during winter-spring (Gallaway et al. 1979a) when they may be briefly important from a trophic standpoint (e.g., an alternate food source for spadefish in the absence of sufficient plankton). They undoubtedly are important in that they provide cover or habitat for small forms such as amphipods (important as food to large cryptic species [those living in the recesses formed by the biofouling community] and small reef fish) which also attain greatest seasonal densities during winter (Gallaway et al.

1979a). Information from all of the above aspects of community relationships are necessary to reduce the uncertainties associated with making an integrated assessment of the significance of observed impacts from oil and gas production activities on the environment and biota of the BOF.

Effluent Discharge and Related Sampling

An estimate of the rate of produced water discharge from production platform 296B was made during each of the summer, fall, winter and spring seasons. Estimates were based upon samples taken at 4-h intervals over a 24-h period. Samples consisted of allowing a 21-ℓ container to fill with produced water from the discharge pipe with the time required for filling recorded. Three replicates were taken at each 4-h interval. In conjunction with this sampling, produced water samples were obtained from the discharge, and seawater and surficial sediment samples were taken on a "bullseye" sampling array as described by Middleditch and West (1980, Work Unit 2.2.1; hydrocarbons, biocides and sulfur), Tillery (1980, Work Unit 2.4.2; trace metals) and Brooks et al. (1980, Work Unit 2.3.2; surficial sediments and suspended particulates). All of the planned 586 samples in the above categories were obtained and transferred. In addition to these, 24 sediment trap, 80 barnacle and 12 fouling mat samples, respectively, were provided to Dr. Middleditch (Work Unit 2.4.1, hydrocarbons) and 24 barnacle and 24 fouling mat samples were provided to Mr. Tillery (Work Unit 2.4.2, trace metals) for analyses of contaminants. All of the total 750 planned samples to be taken by the biofouling work unit (2.3.8) for other work units were obtained and transferred. Results of most of these analyses have been reported by the aforementioned investigators, and will be used by us in making the impact analysis during the final year (1979-1980).

Respirometry

Respirometry experiments were performed *in situ* using specially constructed chambers which were temporarily attached to platform support members. Two models of respirometers were used. The first model consisted of a wooden base with an attached clear acrylic hemisphere and the second was a wooden box with a clear plexiglass cover. In each, a battery-operated stirrer was used to provide water circulation to prevent localized pockets of oxygen depleted water and to sustain flow across the dissolved oxygen measuring probe. Oxygen changes within the respirometer were measured with a YSI dissolved oxygen meter.

Oxygen changes were measured under a variety of conditions during each season. Variables included time of day and the concentration of produced water which was introduced. Produced water was added to the enclosed system so as to provide a measure of its effects on the biofouling community.

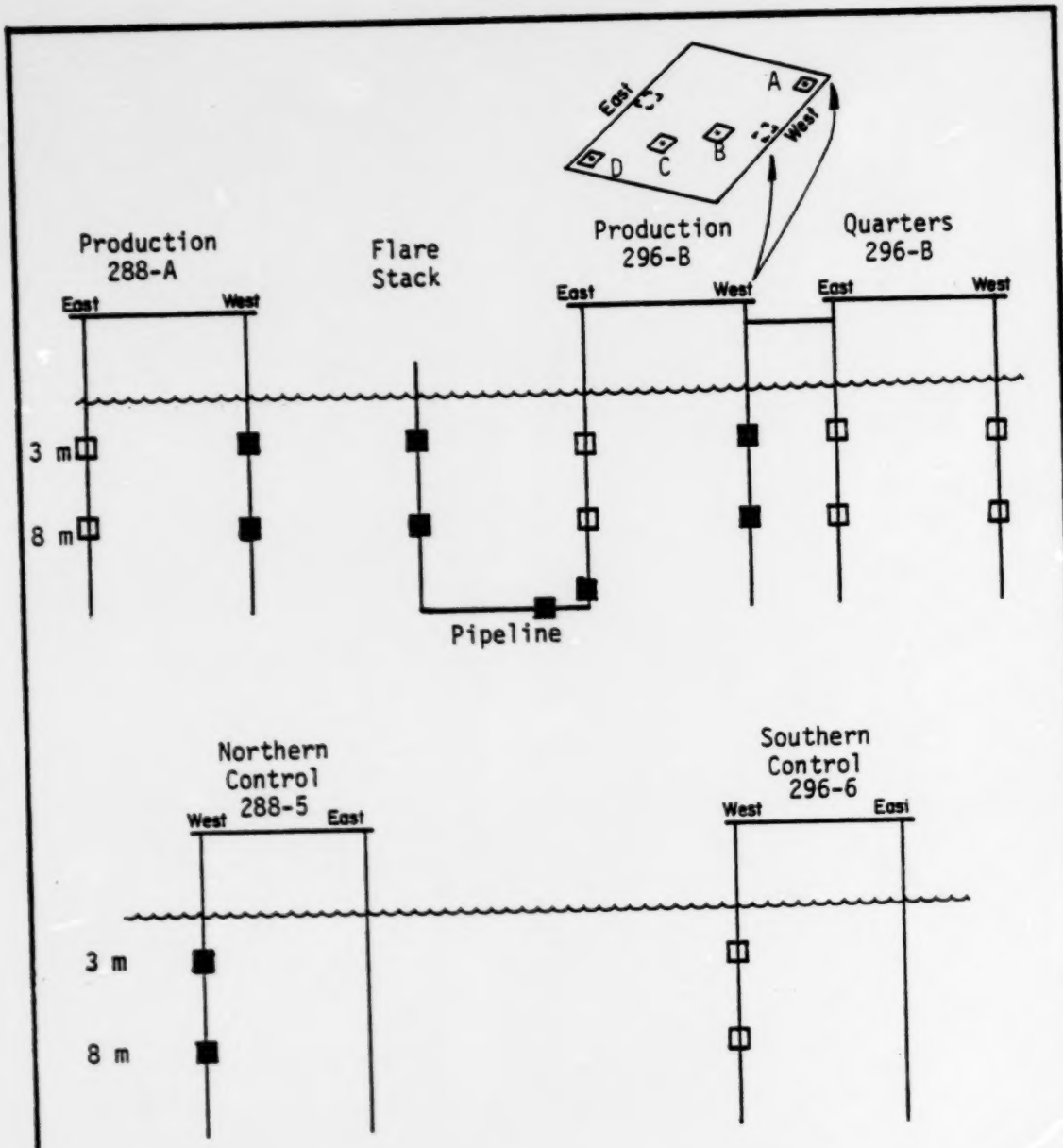
Effects Based Upon Harvest Sampling

A total of 28 stations were harvested during summer 1978 and 10 were harvested during winter 1979 (Fig. 1). Sampling at each station consisted of collecting all of the attached fouling growth contained within three or four 25- x 25-cm quadrats. Quadrats were delineated using a specially fabricated template. The template was a 0.5- x 1.0-m metal frame sectioned into 8 quadrats (Fig. 2). At each station, the template was securely attached to a platform support member. Once attached, either the "A" or "B" grid pattern was randomly selected and each cell was photographed. Divers using putty knives and hatchets collected the fouling growth from each 25- x 25-cm quadrat and placed it into labeled plastic bags. Samples were then transported to the surface, transferred to plastic jars, labeled and preserved in 7% buffered formalin. Analyses of faunal components were based upon three replicates taken at each station sampled regardless of season, whereas analyses of floral components (macroalgae) were based upon only one replicate taken from each of the 10 stations sampled during both summer and winter. The sampling design was not ideal, but represented a realistic compromise considering seasonal vagaries, logistics and costs.

In the laboratory, faunal samples were analyzed for total wet weight, shell wet weight, number of live and dead barnacles (*B. tintinnabulum*, *Balanus* spp.), and number and weights of macrocryptic fauna. Carapace length and width data, respectively, were obtained for the cryptic crustaceans, pistol shrimp (*Synalpheus fritzmuelleri*) and stone crab (*Menippe mercenaria*). Total wet weight of the samples was obtained by direct weighing to the nearest 0.1 g. Macrocryptic fauna were removed from the samples, sorted by taxa, counted and weighed on an analytical balance. Carapace lengths or widths were measured using a graduated rule or caliper. Shell wet weight was measured after all mat (sponges, hydroids, etc.) organisms were removed from the shelled organisms (mostly barnacles) by scraping. Wet weight of the "mat community" was estimated by subtracting shell weight from total sample weight.

Floral samples were subsampled by weight. The subsample was examined under a dissecting microscope and all macroalgae was removed, identified to the lowest recognizable taxa and weighed on an analytical balance.

Results from our previous studies (Gallaway et al. 1979a) were believed to have adequately described seasonal differences in abundance and biomass of the fouling community. Analyses this year were basically designed to be performed within season and to address (1) effects of discharges based upon the 3- and 8-m deep stations, and (2) compare fouling biomass on an exposed pipeline to that on a 21-m deep station on a platform support. The latter comparison allows an assessment of the habitat value of pipelines. In the former case, the experimental design for the factorial analysis of variance (ANOVA) performed on summer data was:



• Represents 2 stations, 1 each at 3- and 8-m depths

Fig. 1. Locations of sampling sites for measuring areal biomass variations during summer (all stations shown) and winter (■). Stations A-D were also sampled at 3- and 8-m depths.

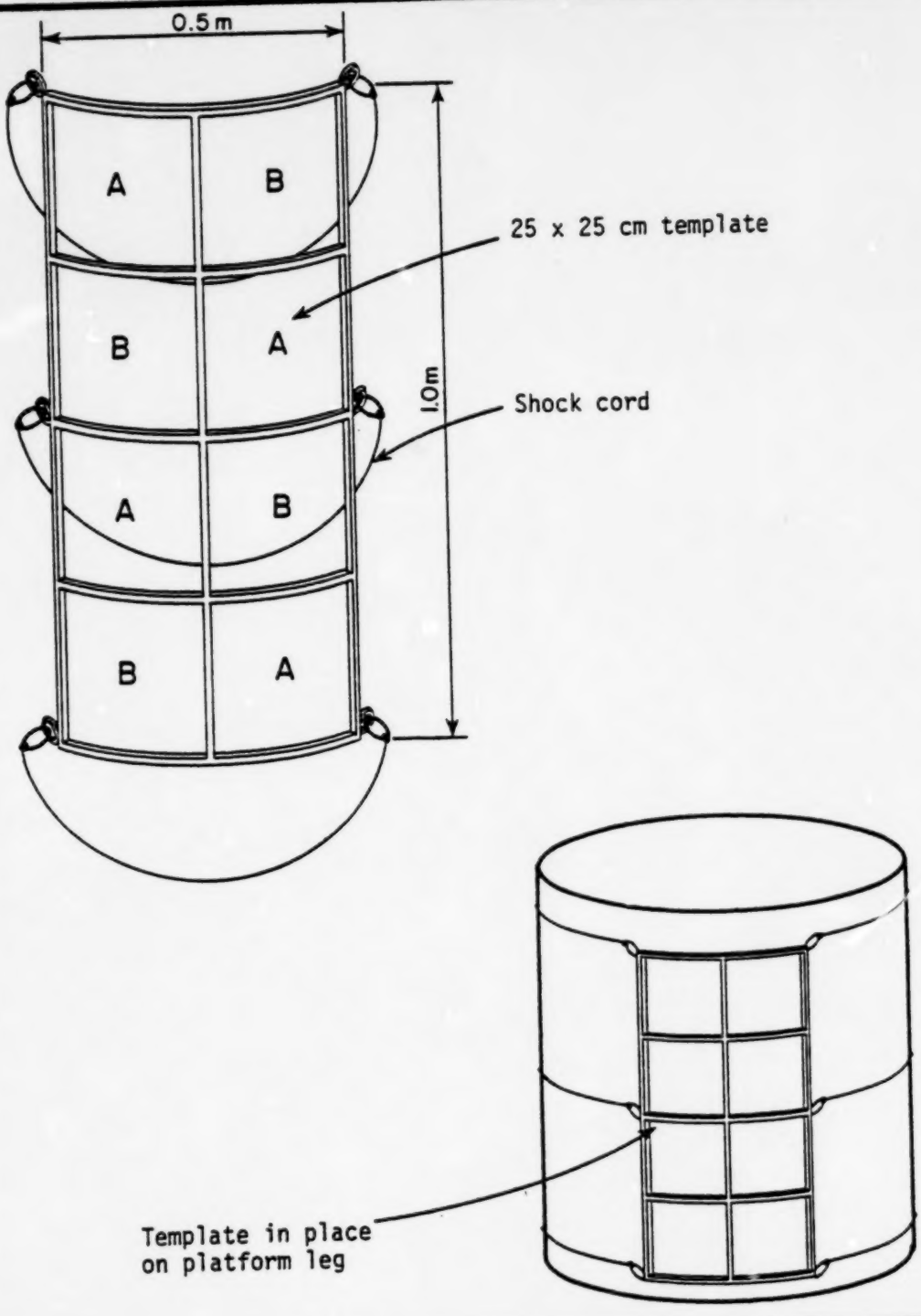


Fig. 2. Diagrammatic representation of scraping templates. Cells labeled A and B represent the two possible sampling schemes.

Source	Degrees of Freedom	Explanation
Total	77	3 replicates x 13 legs (stations) x 2 depths = 78
Stations	12	P296B-W, P296B-E, P296B-A, P296B-B P296B-C, P296B-D, P288A-W, P288-E, F296B, Q296B-E, Q296B-W, S288-5, S296-6 (Fig. 1)
Depth	1	3- and 8-m depths (Fig. 1)
Station x Depth	12	(12 x 1)
Residual	52	(77-25)

In previous studies, we have used a square root transformation of the data based upon examination of variance to mean ratios. This year we performed the analyses on both transformed and untransformed data for comparative purposes. Each analyses yielded the same results in terms of the distribution and level of significant differences. Results presented herein are based upon untransformed data.

Significant differences among stations sampled during summer to determine effects of discharges were evaluated using orthogonal contrasts. The design selected is shown in Table 1. Comparisons of pipeline biomass to that on the platform leg at a 21-m depth were made each season (summer and winter) using a standard t-test. Comparisons of floral data were of a qualitative nature due to the lack of sample replicates.

The winter sampling array was reduced to 10 stations as described above with eight of these used for effects comparison. The basic experimental design was:

Source	Degrees of Freedom	Explanation
Total	23	3 replicates x 4 legs (stations) x 2 depths = 24
Stations	3	P288A-W, P296B-W, F296B, S288-5 (Fig. 1)
Depth	1	3- and 8-m depths (Fig. 1)
Station x Depth	3	(3 x 1)
Residual	16	(23-7)

Table 1. Table of coefficients for orthogonal contrasts used to compare data from biofouling collections taken during summer 1978.

Contrast	STATIONS													Total
	P288A-W	P288-E	P296B-W	P296B-E	P296B-A	P296B-D	P296B-B	P296-C	P296B	Q296-W	Q296-E	S288-5	S296-12	
1. Platforms with discharges *vs* platforms without discharges	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	-11	-11	0
2. Production platforms *vs* Quarters platforms and Flare Stacks	+3	+3	+3	+3	+3	+3	+3	+3	-8	-8	-8			0
3. Production platform 288A *vs* Production 296B	+3	+3	-1	-1	-1	-1	-1	-1						0
4. Production 288A-W (discharge leg) *vs* P288A-E (control)	+1	-1												0
5. Production 296B peripherial legs (296B-W, 296B-A, P296B-D, P296B-E) *vs* interior supports (P296B-B, P296B-C)			+1	+1	+1	+1	-2	-2					-	0
6. Production 296B-W (discharge leg) *vs* P296-A, P296B-D and P296B-E			+3	-1	-1	-1								0
7. Production 296B-A, Production 296B-D (corner legs) *vs* P296B-E				+2	-1	-1								0
8. Production 296B-A (south corner) *vs* P296B-D (north corner)					+1	-1								0
9. Production 296B-B (well casing) *vs* P296B-C (interior leg)							+1	-1						0
10. Flare 296B *vs* Quarters 296B									+2	-1	-1			0
11. Quarters 296B-W (discharge) *vs* Q296B-E										+1	-1			0
12. Satellite 288-5 *vs* Satellite 296-12												+1	-1	0
TOTALS	+9	+7	+8	+6	+4	+2	+3	+1	-4	-6	-8	-11	-11	0

The orthogonal contrasts used to compare stations in terms of data collected during winter were:

Contrast	Stations				
	P288A-W	P296B-W	F296B	S288-5	Total
1. Structures with Discharges (P288A-W, P296B-W, F296B *vs* Satellite S288-5)	+1	+1	+1	-3	0
2. Production *vs* Flare	+1	+1	-2		0
3. P288A *vs* P296B-W	+1	-1			0
TOTALS	+3	+1	-1	-3	0

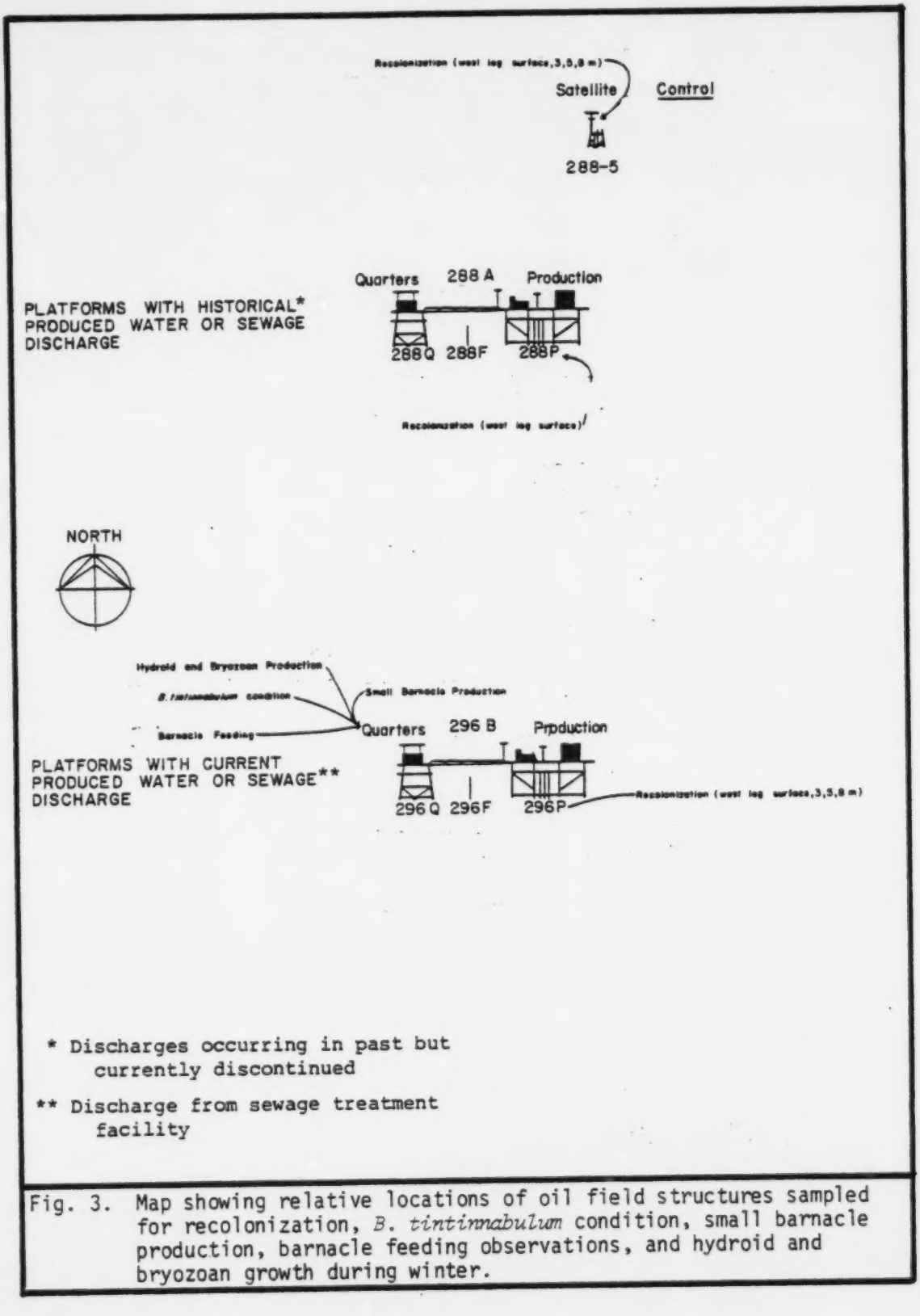
Effects Based Upon Recolonization Sampling

In addition to sampling climax fouling growth to ascertain effects of effluents, structure type and depth, characteristics of new growth communities were measured. Small 25- x 25-cm areas were cleared of existing fouling growth by SCUBA divers at nine locations (Fig. 3) and allowed to recolonize for either ≃ 90- or ≃180-d periods. Ninety-day recolonization samples were collected four times from stations 288P (surface, discharge leg), 296P (surface, 3-, 5- and 8-m depths on west leg) and station 288-5 (surface, 3-, 5- and 8-m depths on the west leg). Three stations (288P, surface; 296P, surface; and 288-5, surface) were collected twice to obtain the 180-d samples.

Recolonization samples consisted of triplicate "jar" samples. A jar sample was taken by placing a glass jar (4.8-cm opening) against the substrate and then carefully sliding a putty knife underneath the fouling growth thereby trapping a circular "pancake" (≃ 18 cm^2) of fouling organisms in the jar. A lid was then placed on the jar, returned to the surface, and the contents preserved in 7% buffered formalin.

Recolonization samples were analyzed for total wet weight and total wet weight of each barnacle species in the sample. Growth characteristics of dominants (barnacles) can be inferred by comparisons of 90- and 180-d samples which had started colonizing concurrently.

This part of the study was designed such that we could evaluate the effects of the produced water discharges from P296B (continuous discharge) and P288A (intermittent discharge) on new growth at the surface directly beneath the outfall by comparing samples taken from these areas to samples taken at a surface zone on Satellite 288-5 (without a discharge). In essence, these samples evaluate short-term effects (90- and 180-d periods), an assessment of long-term effects is provided by results of the harvest sampling program. The experimental design for the 90-d surface samples was:



* Discharges occurring in past but currently discontinued

** Discharge from sewage treatment facility

Fig. 3. Map showing relative locations of oil field structures sampled for recolonization, *B. tintinnabulum* condition, small barnacle production, barnacle feeding observations, and hydroid and bryozoan growth during winter.

Source	Degrees of Freedom	Explanation
Total	35	3 stations x 4 seasons x 3 replicates
Structure	2	P296B, P288A, S288-5
Season	3	(1) spring to summer; (2) summer to fall; (3) fall to winter; (4) winter to spring
Structure x Season	6	(2 x 3)
Residual	24	(35-11)

and a similar design was used for the 180-d samples:

Source	Degrees of Freedom	Explanation
Total	17	3 stations x 2 seasons x 3 replicates
Structure	2	P296B, P288A, S288-5
Season	1	(1) summer to winter; (2) winter to summer
Structure x Season	2	(2 x 1)
Residual	12	(17-5)

Means were compared using either a Duncan's Multiple Range test or an appropriate orthogonal contrast. Where significant interaction differences were evident, means were compared graphically.

Two legs (P296B, discharge leg and west leg of S288-5) were sampled at 3-, 5- and 8-m depths in addition to the surface sample. The purpose of these samples was to identify the vertical extent of any effects of the produced water discharge on new growth. The experimental design for analysis of these data was more complex:

Source	Degrees of Freedom	Explanation
Total	95	2 stations x 4 depths x 4 seasons x 3 replicates
Structure	1	P296-B and S288-5

...cont'd

Source	Degree of Freedom	Explanation
Depth	3	(0-, 3-, 5- and 8-m depths)
Season	3	(1) spring to summer; (2) summer to fall; (3) fall to winter and (4) winter to spring
Structure x Depth	3	(1 x 3)
Structure x Season	3	(1 x 3)
Season x Depth	9	(3 x 3)
Structure x Depth x Season	9	(1 x 3 x 3)
Residual	64	(95-31)

Means were compared using a Duncan's Multiple Range test in the absence of significant interactions, or graphically in the presence of significant interaction terms.

Condition of *Balanus tintinnabulum*

Samples of thirty large barnacles (*B. tintinnabulum*) were collected each season by divers for comparisons of condition. During August and December, large barnacles were collected at 8-m depths on 296Q. During the latter part of the December field sampling effort, we expanded the sampling scheme to include barnacles from 1-m depths on the discharge leg of 296P and at 1-m depths on 296Q for comparisons of the effects of the produced water discharge. Subsequent collections during February, and April were made at 1-m depths on 296Q.

Collections were obtained by hand or using a hatchet. Similar size-range barnacles were selected at all locations. The barnacles were placed in a mesh bag and, upon surfacing, the sample was preserved in buffered formalin.

In the laboratory, opercular structures of each selected individual were removed and all meat was extracted. The meat was suctioned dry and wet weight (g) was obtained. The meat was placed next in crucibles and dried at 100°C for 24 h in order to obtain dry weight (g). The opercular structures were cleaned and measured to the nearest tenth of a millimeter using calipers. The average of the two scuta or terga measurements were recorded. The barnacle cavity volume was obtained using water administered by a buret. The cleaned cavity was filled to capacity and measurements of volume taken to the nearest 0.1 ml.

The relationship of the amount of meat weight of a barnacle to its cavity volume provides a measure of condition. This relationship was found to be curvilinear having the general form:

$$W = a\ V^b$$

where W is meat weight, V is cavity volume and a and b are constants derived from the data. This relationship can be linearized by applying a log transformation such that:

$$\log W = \log a + b \log V$$

In the linear form, analysis of covariance (AOCV) techniques can be used to compare the regressions. The AOCV technique we selected for use involved the application of a General Linear Model Theory Lack of Fit Test (R.J. Fruend, Institute of Statistics, Texas A&M University, pers. comm.) in which the overall regression relationship was described and tested to determine if a single relationship best described all six cases. If several regression relationships among cases were indicated, (i.e., statistical significance), subsequent tests determined whether these relationships were best described as either (1) separate, yet parallel, relationships for each case or (2) separate regressions having unequal slopes. If separate parallel relationships were indicated, significant differences in predicted meat dry weight at an adjusted mean cavity volume were evaluated using Duncan's Multiple Range Tests.

Feeding of *B. tintinnabulum*

During summer, feeding periodicity of *Balanus tintinnabulum* was measured by diver observation every 4 h throughout a 24-h period. Three 5-min counts of the number of barnacles exhibiting cirral activity within predetermined clusters of 10-15 individuals were recorded by divers. During fall and winter, a time-lapse movie camera was used to photograph a small area of fouling community. A photograph was taken every 25 sec during a 24-h period. The resulting film was analyzed to provide a precise and quantitative measure of barnacle activity. During winter 1979, diver observation at mid-day, after dusk and before dawn supplemented the photographic technique.

Concurrent with the barnacle feeding observations, 5-7 live barnacles were collected and maintained in 1-ℓ jars for a predetermined period of time to measure fecal pellet production. After the designated time (4 h in summer and 4, 8, and 12 h in winter) barnacles and fecal material were preserved in 7% buffered formalin. In the laboratory, fecal pellet wet weight, total wet weight and soft tissue wet weight of the barnacles were obtained using an analytical balance.

Production of the Small Barnacle, *B. amphitrite*

A 0.25- x 1.0-m area on 296Q was scraped clean of fouling growth. This "production" area was located at a depth of 8 m (Fig. 3). At periodic intervals ¼ of the area (0.0625 m^2) was harvested by divers and the resulting sample preserved in 7% buffered formalin.

The numbers of living and dead barnacles of the dominant species were counted. Total wet and dry weights were measured to the nearest 0.01 g. The production rate method described by Crisp (1971:213) for a population with no recruitment was used for calculating production of the initial barnacle set.

Production of the Hydroid, *Tubularia crocea*

A simple field experiment was performed to obtain an estimate of the net growth rate or production of this hydroid during its winter season of bloom. Size and biomass characteristics of typical colonies were determined by collecting representative colonies at both the beginning and end of the experiment. We also simulated effects of grazing by clipping parts of colonies and comparing rate of regrowth in clipped areas, to rate of growth in undisturbed parts of the some colony.

The hydroid growth experiment was initiated on 13 March 1979. Divers collected three representative colonies in their entirety at a depth of approximately 2 m on the 296 Quarters Platforms. These samples were used to characterize whole colonies in terms of total numbers of stalks or branches and total biomass. Three additional colonies were sampled for test purposes. Approximately half of each of these colonies was harvested using scissors and an underwater vacuum device to collect the stalks as they were severed. These samples provided the initial estimates of length and weight of individual stalks at time 0. Sampled colonies were marked using a nylon line tied to the cross member of the structure.

Following a 23-d interval, the test colonies were relocated and harvested on 5 April 1979. New growth from the sites previously clipped were taken first, with the remainder of the colony taken afterwards. Three additional whole colonies were also collected for characterization purposes. All hydroid samples were containerized and preserved in formalin as soon as possible following collection.

In the laboratory, the whole colonies which had been collected were weighed to obtain total wet weight (to the nearest 0.1 g) and the stalks were counted to determine the number of stalks comprising each colony. A sample of 20 representative stalks from the first set of clippings taken from 2 of the 3 test colonies partially harvested were individually measured to the nearest mm using a metric rule, and weighed for wet weight using an analytical balance. Identical procedures were followed to obtain

lengths and weights for the subsequent samples (uninterrupted growth and new growth at clipped sites) taken from the test colonies.

Production of the Bryozoan, *Bugula neritina*

The branching bryozoan *Bugula neritina* is similar to the hydroid, *T. crocea* in that it blooms during winter. Whereas the hydroid colonies grow in scattered, discrete clumps, the bryozoan forms a luxuriant, almost ubiquitous, cover of low relief. During seasons other than winter, these species, although abundant, can only be carefully discerned among the remainder of the mat community because of their small size. However, during winter, they tower above and completely dominate the appearance of the mat community, often even obliterating barnacles from view.

Samples taken from three belt transects were used to estimate branching bryozoan growth during a winter-spring period. A 5- x 100-cm belt transect was delineated using 3-mm line secured to a cross member at a depth of 8 m on the 296Q platform (Fig. 3). Branching bryozoans and hydroids were collected at the time of transect establishment by clipping with scissors and placing the material into plastic bags. The transects were initially sampled on 6 March 1979 and were left in place to allow regrowth until the end of the spring sampling effort. Subsequent collections were made as described above on 8 May 1979 (one transect) and on 16 May 1979 (the remaining two transects). As the transect lines had been colonized by *T. crocea*, they were also retrieved and preserved for laboratory analysis.

In the laboratory samples from within the transects were weighed to the nearest g using an analytical balance to obtain an estimate of the net biomass produced over the sampling period. The number of hydroid stalks which had established on the transect lines was also determined.

RESULTS AND DISCUSSION

All planned samples within the scope of the contract were obtained and analyzed. These included 48 effluent discharge samples, 4 respirometry experiments, 144 harvest samples, 144 recolonization samples, 120 barnacle condition samples, 2 barnacle feeding experiments, 4 small barnacle production samples, 9 hydroid production samples and 12 bryozoan production samples. All data were tabulated in appropriate formats and codes and have been submitted to project data management (Work Unit 2.2.8). In addition to the above, all of the 750 planned samples of the environment and biota were obtained and transferred *vis a vis* project protocols to other work units as described above. Work performed outside the scope of the contract but reported herein includes long-term time lapse photography to document the seasonal "decay" of hydroid colonies, additional respirometry experiments performed on-board the platform, a simple bioassay experiment and additional barnacle samples for condition analysis.

Effluent Discharge

The flow rate of produced water discharged overboard at production platform 296B varied with time of day and season. As depicted in Fig. 4, the flow rate was highly variable. On each day sampled, maximum flow occurred from 1300-2300 h. Maximum rate of discharge (259,000 ℓ/d or 1630 bbl/d) occurred in May while the lowest rate (other than no flow) was in September (170,981 ℓ/d or 1075 bbl/d). The average discharge rate for the four days sampled was 221,337 ℓ/d (= 1392 bbl/d). Using the average flow as a representative value, the annual discharge of produced water into the Gulf of Mexico from this structure was estimated to be 8.08×10^7 ℓ or 5.08×10^5 bbl.

In the final year, these data will be used in conjunction with the data describing contaminant concentrations in the produced water, environment and biota to determinant contaminant "pools" or sinks and to evaluate fates of contaminants given the oceanographic process data which will be provided by Work Unit 2.3.9.

Respirometry

During the summer, the oxygen consumption rate for 0.16 m^2 of fouling community was measured *in situ* under various conditions. The fouling community had a total wet weight of 1551.7 g and included 29 *Balanus tintinnabulum*, 159 *Balanus* spp., 5 stone crabs, 7 pistol shrimp, 2 crested blennies, and 3 seaweed blennies. Baseline oxygen consumption rates were determined at night, mid-day, and late afternoon. At night, oxygen was consumed at a rate of 12 mg/h. During mid-day, oxygen production equalled oxygen consumption. Oxygen was consumed at a rate of 0.73 mg/h during late afternoon. Subsequent experimental work occurred during late afternoon. When the system contained under the respirometer was subjected to a 25% solution of produced water in seawater, oxygen consumption increased at a rate of 46.5% greater than the control. The system's macrofouling component exhibited a 67.6% increase in oxygen consumption. System components other than the macrofouling increased oxygen consumption by 38.6% over the control rate.

Respirometry experiments performed *in situ* in fall were diminished in scope by various equipment failures. Three seawater control runs were performed. Daytime experiments starting at 1415 h and 1045 h showed identical oxygen depletion rates (0.50 mg/ℓ/h). The night experiment exhibited a depletion rate of 1.35 mg/ℓ/h.

Respirometry experiments were also performed on the platform during the fall. Four nalgene bottles of 4000-ml capacity were used as test containers. Two of these contained seawater for a control and two were filled with a 10% mixture of produced water and seawater. Equivalent-sized clumps of barnacles and fouling mat were placed in one of each of the control and treatment containers. Oxygen decline in all four containers was measured at 5-min intervals over a 1-h period once during the

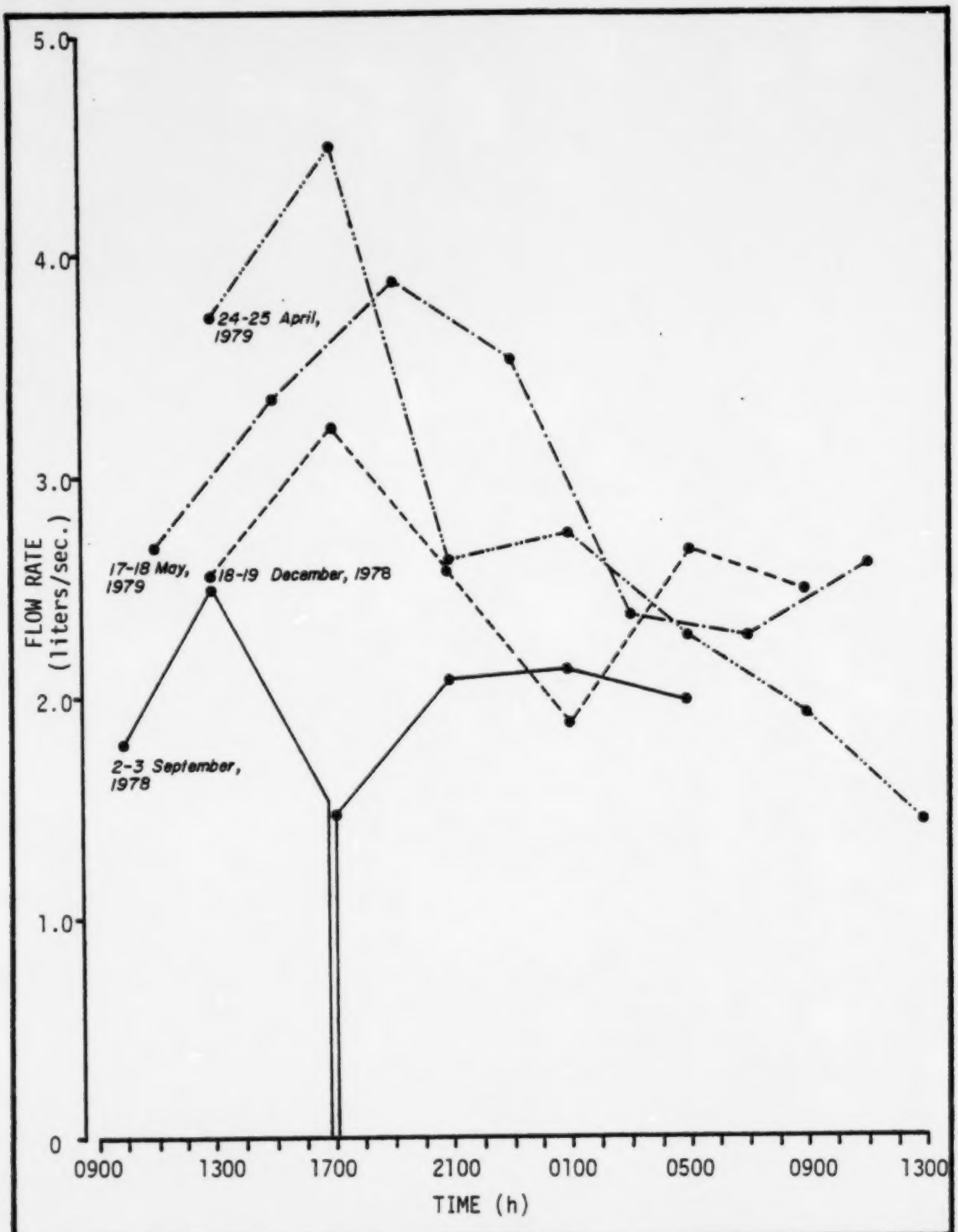


Fig. 4. Discharge rates of produced water from production platform 296B, 1978-1979.

day and once at night. Fresh solutions of seawater and seawater-produced water were used for each run.

In all cases, dissolved oxygen levels in the seawater solution at the initiation of the experiments were 0.2 to 0.3 mg/ℓ higher than concentrations observed in the treatment solutions (initial values ranged from 6.2 to 7.1 mg/ℓ and none declined below 4 mg/ℓ in the 1-h experiments). In the seawater control without barnacles, oxygen levels increased from 7.1 to 7.3 mg/ℓ at night and remained at 6.7 during the day experiment. In the 10% produced water-seawater mixture without barnacles oxygen levels dropped from 6.8 to 6.7 mg/ℓ at night and from 6.4 to 6.3 mg/ℓ during the day experiment. Oxygen levels in containers having barnacles declined during both day and night experiments. In the seawater controls, rates of decline were 1.2 and 1.8 mg/ℓ for day and night, respectively. In the treatment experiment, comparative rates of decline were 1.5 and 2.1 mg/ℓ for day and night, respectively.

Respirometry experiments during winter were all performed *in situ* and included day and night controls, day and night controls with fouling organisms removed, 1% produced water treatment (day), 10% produced water treatment (day and night) and 10% produced water with fouling organisms removed. Oxygen concentrations in the respirometer declined in all experiments.

In the control experiment with fouling organisms present, oxygen decreased at a rate of 1.85 and 1.95 mg/ℓ/h during day and night respectively. When the fouling organisms were removed from the respirometer, the respective rates were 0.3 and 0.6 mg/ℓ/h. These values indicated a significant amount of oxygen consumption was attributable to the fouling organisms rather than planktonic sources in the enclosed water.

Oxygen declined at a rate of 2.0 and 1.7 mg/ℓ/h in the 1% and 10% produced water day-treatment, respectively. During the night treatment of 10% produced water-seawater the rate of decrease was 2.2 mg/ℓ/h. With 10% produced water in seawater with fouling organisms removed from the vessel, the rate of oxygen decline was 0.4 mg/ℓ/h.

Results of these experiments indicated a 10% produced water treatment inhibits oxygen consumption during the day but increases oxygen consumption at night. The reasons for these variations was probably a complex interaction of changes in respiration rates coupled with changes in photosynthetic processes. Based upon night values, oxygen consumption apparently increased with the addition of produced water to the system.

During spring, relatively high rates of oxygen consumption were observed in both control and produced water treatment experiments performed *in situ*. The oxygen depletion rate was less with the 10% produced water than with the control. Rates were 3.05 mg/ℓ/h and 3.15 mg/ℓ/h, respectively. The highest value of oxygen depletion (3.50 mg/ℓ/h) was at night. Results of this set of experiments suggest that produced water either inhibits rates of respiration or stimulates photosynthesis.

The respirometry experiments, although crude, provided information useful for making the impact assessment. In overview, the results indicate (1) that biofouling primary production rates were low and (2) that produced water not only had oxygen-demand attributes in its own right, but also increased oxygen demand of the systems under study, particularly the biofouling component.

Harvest Sampling

Results from the harvest sampling program are presented below by selected response variables within season. Pertinent seasonal comparisons are discussed as warrented by the amount of data obtained.

Total Biomass

During summer, average total biomass levels on the structures sampled ranged from a low of about 7.9 kg/m^2 at the 3-m depth on the discharge leg of Production Platform 288A to a high of nearly 27 kg/m^2 at a 3-m depth on the flare stack of 296B. Results of the ANOVA performed on these data, yielded the following results.

Source	DF	S.S.	M.S.	F
Total	77	10398900.08		
Station	12	4821972.60	401831.05	4.49*
Depth	1	31244.02	31244.02	0.35
Station x Depth	12	891769.33	74314.11	0.83
Residual	52	4653914.13	89498.35	

*Significant at the 1% level.

A summary of the results of the orthogonal contrasts is provided in Fig. 5. Total biomass on quarters and flare stack structures ($\bar{x}$ = 19.9 kg/m^2) was statistically higher at the 1% level than the biomass representative for production platforms ($\bar{x}$ = 15.2 kg/m^2). The biomass measured at the flare stack was statistically higher at the 5% level than the biomass at the quarters platform. The biomass at the southern control satellite (296-12) was higher (5% level) than the northern control satellite (288-5). Respective mean biomass values were 20.8 and 15.2 kg/m^2 (Fig. 5). Biomass on the well casing sampled near the discharge was significantly lower (1% level) than biomass on a nearby interior leg further removed from the discharge. No significant differences were observed between the discharge leg and other peripheral legs at either of production platforms 288A or 296B.

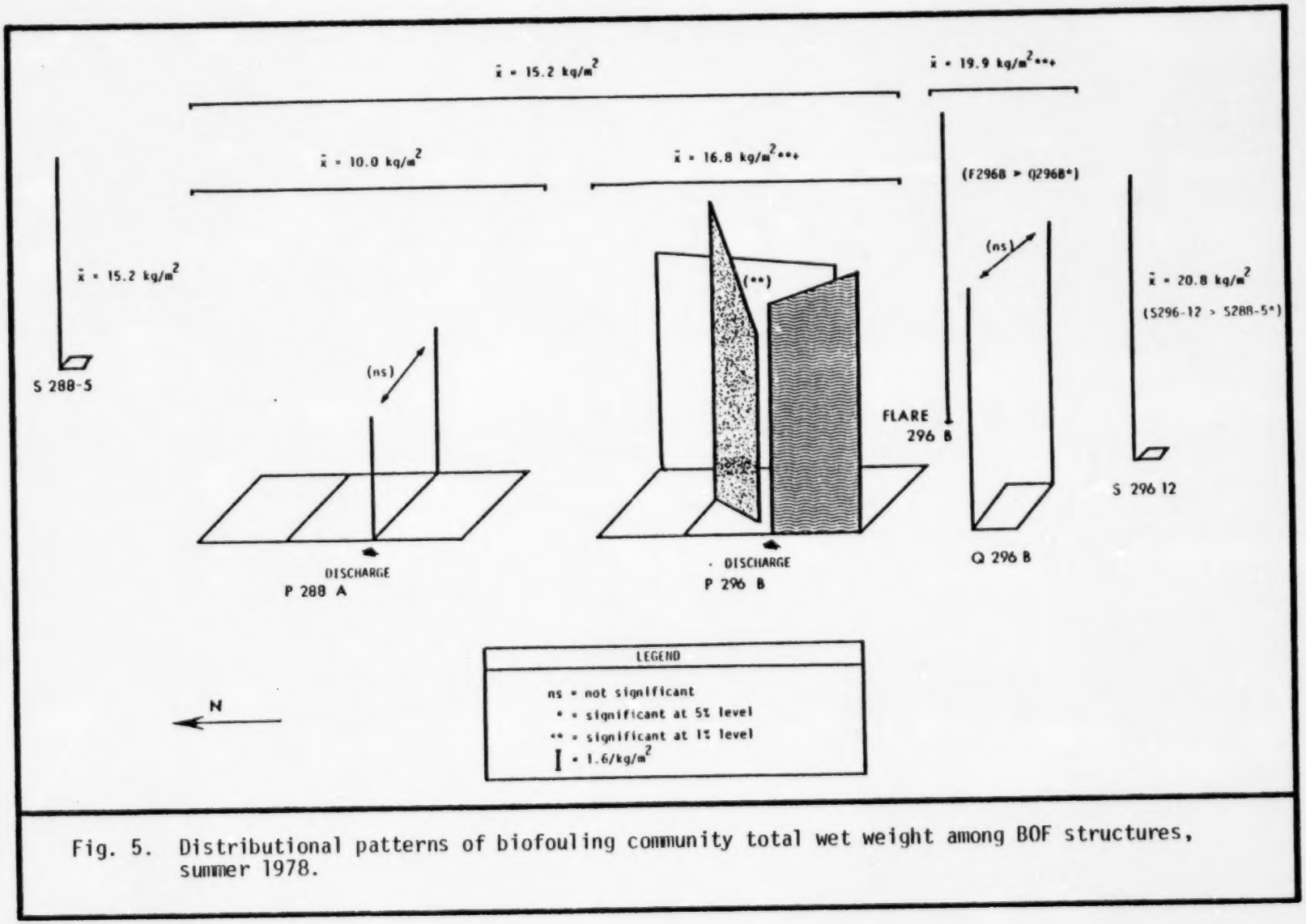


Fig. 5. Distributional patterns of biofouling community total wet weight among BOF structures, summer 1978.

Average biomass levels of the fouling community on BOF structures sampled during winter ranged from a low of 18.2 (3 m, Flare 296B) to a high of 28.1 kg/m^2 at a 3-m depth on S288-5. Results of the ANOVA performed on these data were:

Source	DF	S.S.	M.S.	F
Total	23	3319943.24		
Station	3	561193.27		1.17
Depth	1	15070.08		0.09
Station x Depth	3	196192.84		0.41
Residual	16	2547487.05		

Significant differences were not indicated.

The above findings are in direct contrast to those of last year which included surface sampling and yielded significant differences between the discharge and other peripheral legs and complementary station x depth interactions in terms of the distribution of total biomass. This information would indicate that the statistically significant effects of produced water on fouling biomass are limited vertically to a depth of less than 3 m.

Fouling Mat Biomass

The mean biomass of this system component ranged from 0.7 to 3.0 kg/m^2 during summer but varied greatly among structures and within sample replicates. Significant differences were not indicated among stations, between depths or in the interaction term:

Source	DF	S.S.	M.S.	F
Total	77	542098.13		
Station	12	125905.32	10492.11	1.80
Depth	1	19808.32	19808.32	1.33
Station x Depth	12	93496.73	7791.39	1.33
Residual	52	303887.76	5843.99	

During winter, average biomass of the fouling mat ranged between 3.3 kg/m^2 at an 8-m depth on the 296B flare stack to a high of 10.7 kg/m^2 at the 3-m depth on satellite jacket 288-5. Significant differences were observed:

Source	DF	S.S.	M.S.	F
Total	23	696546.01		
Station	3	345999.78	115333.26	9.08**
Depth	1	65.01	65.01	0.01
Station x Depth	3	147221.21	49073.74	3.86*
Residual	16	203260.01	12703.76	

* Significant at the 5% level

**Significant at the 1% level

In terms of mean fouling mat biomass (kg/m^2) the station by depth differences are summarized:

	Control	Treatment		
Depth	S288-5	P288A	P296B	F296B
3 m	10.7	4.8	7.1	4.6
8 m	7.7	8.5	8.0	3.3

In comparison to the other stations where biomass at 3-m depths was greater than, or about equal to, levels at 8-m depths, the biomass of the fouling mat at a location of 3 m under the discharge of Production Platform 288A was markedly lower than biomass at 8-m depths on the same leg. Results of the orthogonal contrasts of stations showed that biomass at the control satellite was significantly higher (1% level, F = 10.04 at 1/16 df) than that on affected structures and that biomass on Flare 296B was significantly lower (1% level, F = 9.11 at 1/16 df) than that on the production platforms. Although the production platforms exhibited marked station by depth differences, mean levels were not significantly different (F = 0.59 at 1/16 df).

Numbers of *B. tintinnabulum*

Comparisons of the densities of live and dead *Balanus tintinnabulum* present during summer showed significant differences by station and depth, but there were no significant station-depth interactions (Table 2). Densities of both live and dead barnacles were greater at 3-m than at 8-m depths. Densities of live *B. tintinnabulum* were significantly higher (1% level) at flare and quarters ($\bar{x}$ = 727/m^2) than at production platforms ($\bar{x}$ = 418/m^2, Fig. 6). The same trend (significant at 5% level) was noted for dead barnacles (313/m^2 and 232/m^2, respectively, Fig. 7). A notable exception to the trend of density of dead barnacles following that of live barnacles can be seen at each of the discharge legs where relative density of dead barnacles was markedly higher than that of live barnacles (Figs. 6 and 7).

Table 2. Results of ANOVA performed on abundance data for live (a) and dead (b) *Balanus tintinnabulum* on BOF structures during summer 1979.

(a) *Balanus tintinnabulum* (live)

Source	DF	S.S.	M.S.	F
Total	77	37893.29		
Station	12	10555.13	879.59	2.76*
Depth†	1	5635.50	5635.50	17.71*
Station x Depth	12	5154.00	429.50	1.35
Residual	52	16548.67	318.24	

*Significant at the 1% level

†Abundance greater at 3-m than at 8-m depth

See Fig. 6 for results of orthogonal contrasts of stations

(b) *Balanus tintinnabulum* (dead)

Source	DF	S.S.	M.S.	F
Total	77	7257.79		
Station	12	1572.13	131.01	1.95*
Depth†	1	893.54	893.54	13.30**
Station x Depth	12	1298.79	108.23	1.61
Residual	52	3493.33	67.18	

* Significant at the 5% level

**Significant at the 1% level

†Abundance greater at 3-m than at 8-m depths

See Fig. 7 for results of orthogonal contrasts of stations

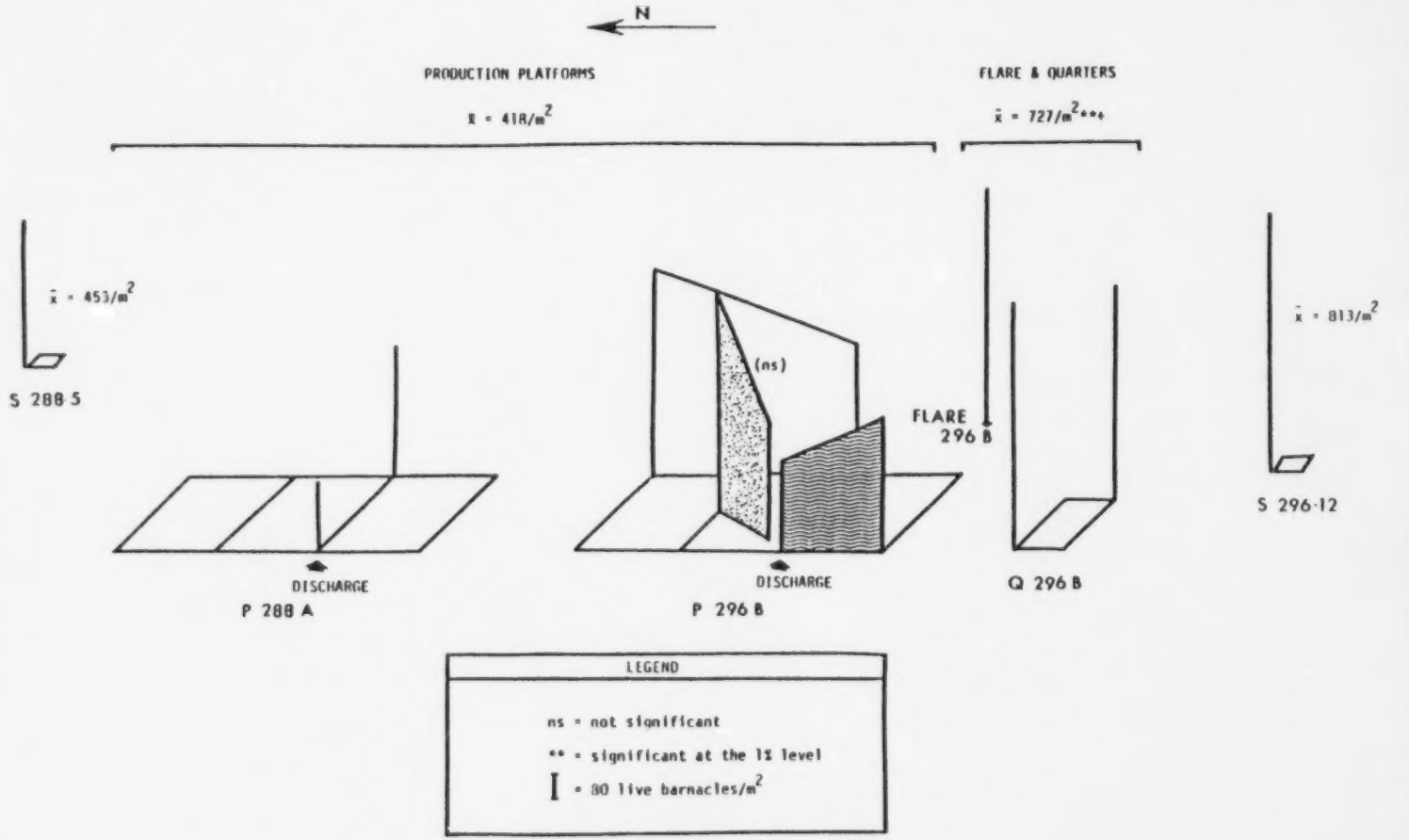


Fig. 6. Distributional patterns of the density of live *B. tintinnabulum* among BOF structures, summer 1978.

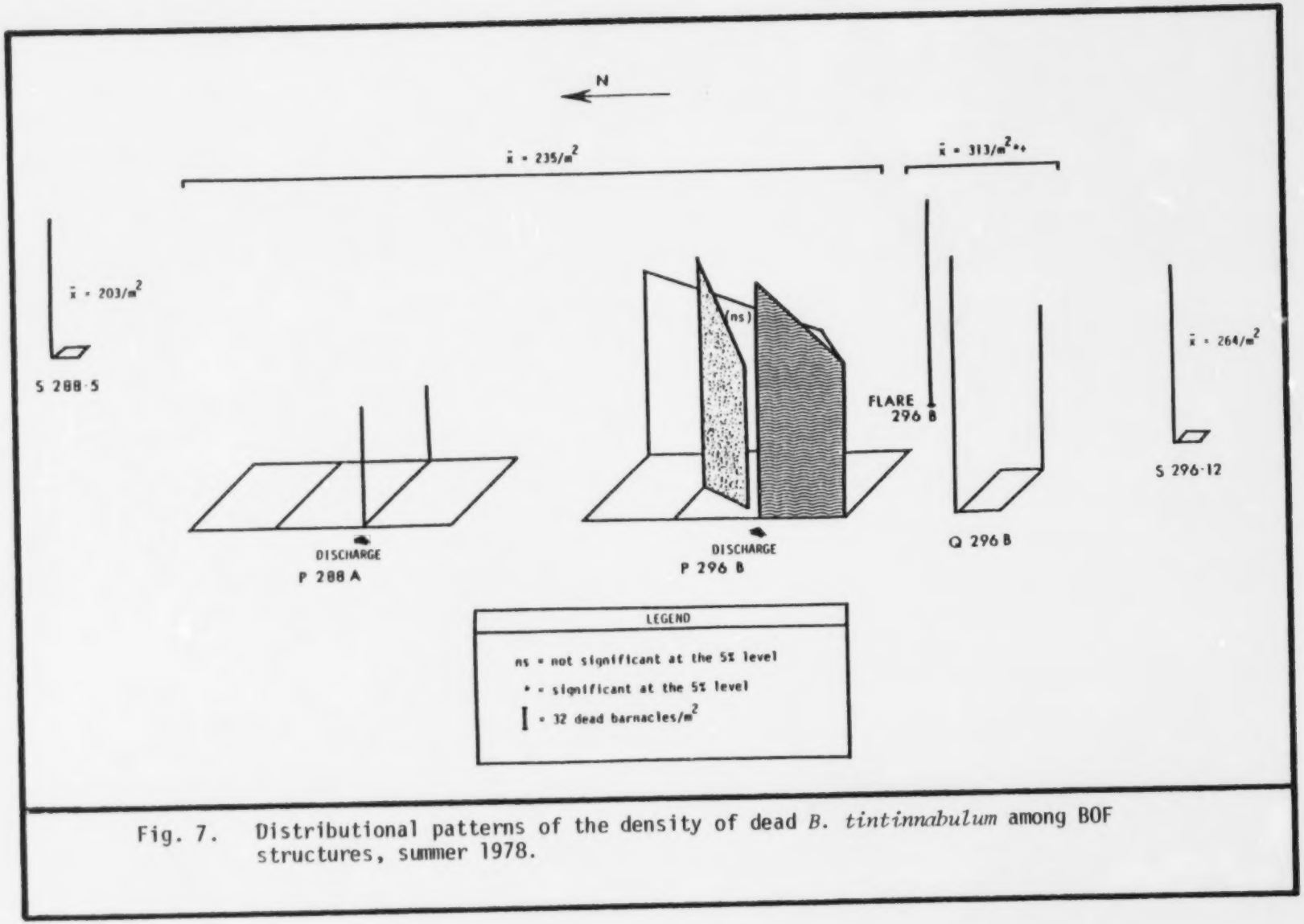


Fig. 7. Distributional patterns of the density of dead *B. tintinnabulum* among BOF structures, summer 1978.

The density of live *B. tintinnabulum* at stations sampled during winter ranged from a low 144/m^2 (8-m deep station at Production Platform 296B) to a high of 629/m^2 at the 3-m depth on the discharge leg of Production Platform 288A. Significant differences were not indicated by the results of the ANOVA:

Source	DF	S.S.	M.S.	F
Total	23	4458.63		
Station	3	1498.13	499.38	3.21
Depth	1	408.38	408.38	2.63
Station x Depth	3	63.46	21.15	0.14
Residual	16	2488.67	155.54	

Significant differences (5% level) in the density of dead *B. tintinnabulum* were observed among stations sampled during winter:

Source	DF	S.S.	M.S.	F
Total	23	1942.50		
Station	3	584.83	194.94	3.26*
Depth	1	66.67	66.67	1.12
Station x Depth	3	335.67	111.89	1.87
Residual	16	955.33	59.71	

*Significant at the 5% level

Results of the orthogonal contrasts were:

Source	DF	M.S.	F
Control *vs* affected	1	144.50	2.13
Productions *vs* Flare	1	400.00	5.89*
Production 288A *vs* 296B	1	40.33	0.59

*Significant at 5% level

Density of dead barnacles was significantly higher on the flare 296B structure ($\bar{x}$ = 373/m^2) than mean density of dead barnacles on the production platforms ($\bar{x}$ = 213/m^2).

Cryptic Macrofauna

In addition to blennies which were studied as part of Work Unit 2.3.5, three species of invertebrates--pistol shrimp, stone crabs and the brittle star, *Ophiactis savignyi*--dominated (in terms of both numbers and biomass) the cryptic macrofauna (as opposed to microfauna such as amphipods, copepods, etc.) associated with the barnacle community on BOF structures investigated during the summer and winter periods of 1978-1979. Of these, we believe the pistol shrimp and brittle star carry-out their entire life cycle as part of the reef community, whereas the stone crab is believed mainly recruited from the plankton and relatively short lived (probably $\leq$ 1 year). Stone crabs are apparently able to flourish in the fouling community until they grow too large to find refuge among the barnacle habitat. Although a few large individuals were sometimes seen in the angles and guides of platform pipes and among the bottom debris, none over 33-cm carapace width were taken in the sampling program. When the crabs outgrow the cover provided by the barnacles, most are probably harvested by predators such as sheepshead.

As described below, population density of the brittle star is probably regulated on a seasonal basis by the availability of cover (or food?) provided by the mat community. In contrast to stone crabs, pistol shrimp do not attain sizes as adults which exceed the protection afforded by the barnacle shells. Further, the barnacle cover (or habitat) is more stable on a seasonal basis than is the mat community. A summary of data from the 3- and 8-m deep stations sampled during both the summer and winter seasons shows pistol shrimp densities were about equal between seasons, brittle stars were markedly more abundant in winter than in summer and stone crabs were more abundant in summer than in winter (Table 3).

Pistol Shrimp. Although population densities were equivalent between seasons, size by season differences were apparent (Fig. 8). In general, neither the smallest nor, to some degree, the largest specimens were represented during winter. Recruitment from reproduction apparently occurred in spring. The general absence of the largest specimens during winter suggests that older individuals which spawn in spring or summer may not survive to the following winter.

Results of both the summer and winter ANOVAs performed on pistol shrimp abundance data indicated significant differences between depths (Table 4). In each case abundance was significantly greater at 8-m depths as opposed to abundance at 3-m depths. As will be shown below, the opposite depth distribution was indicated for stone crab, a potential predator on pistol shrimp.

Differences in levels of abundance of pistol shrimp among stations were not statistically significant (Table 4). Nevertheless, the spatial distribution of pistol shrimp observed for production platforms during summer 1978 (Fig. 9) was of particular interest in that it closely resembled the trends shown by the dead *B. tintinnabulum* data for these platforms (compare Figs 9 and 7). Dead barnacles, particularly those too small for blennies, probably represent ideal habitat for pistol shrimp.

Table 3: Mean densities (number/m^2) of cryptic organisms during summer 1978 and winter 1979.

Station	Pistol Shrimp		Brittle Stars		Stone Crabs	
	Summer	Winter	Summer	Winter	Summer	Winter
296P (discharge leg)						
3m	27	123	5	0	53	5
8m	411	187	0	101*	0	0
296 Flare						
3m	43	53	91	0	32	0
8m	80	165	32	0	0	5
288P (old discharge leg)						
3m	176	69	763	32	27	32
8m	501	205	912	95	5	11
288-5 (control)						
3m	107	155	2848	34,331	64	16
8m	336	251	1520	7,675	16	16
$\bar{x}$ Density	210	151	771	5,279	25	11

*Represents *Ophiothrix* sp.; the common brittle star, *Ophiactus savignyi* were not collected.

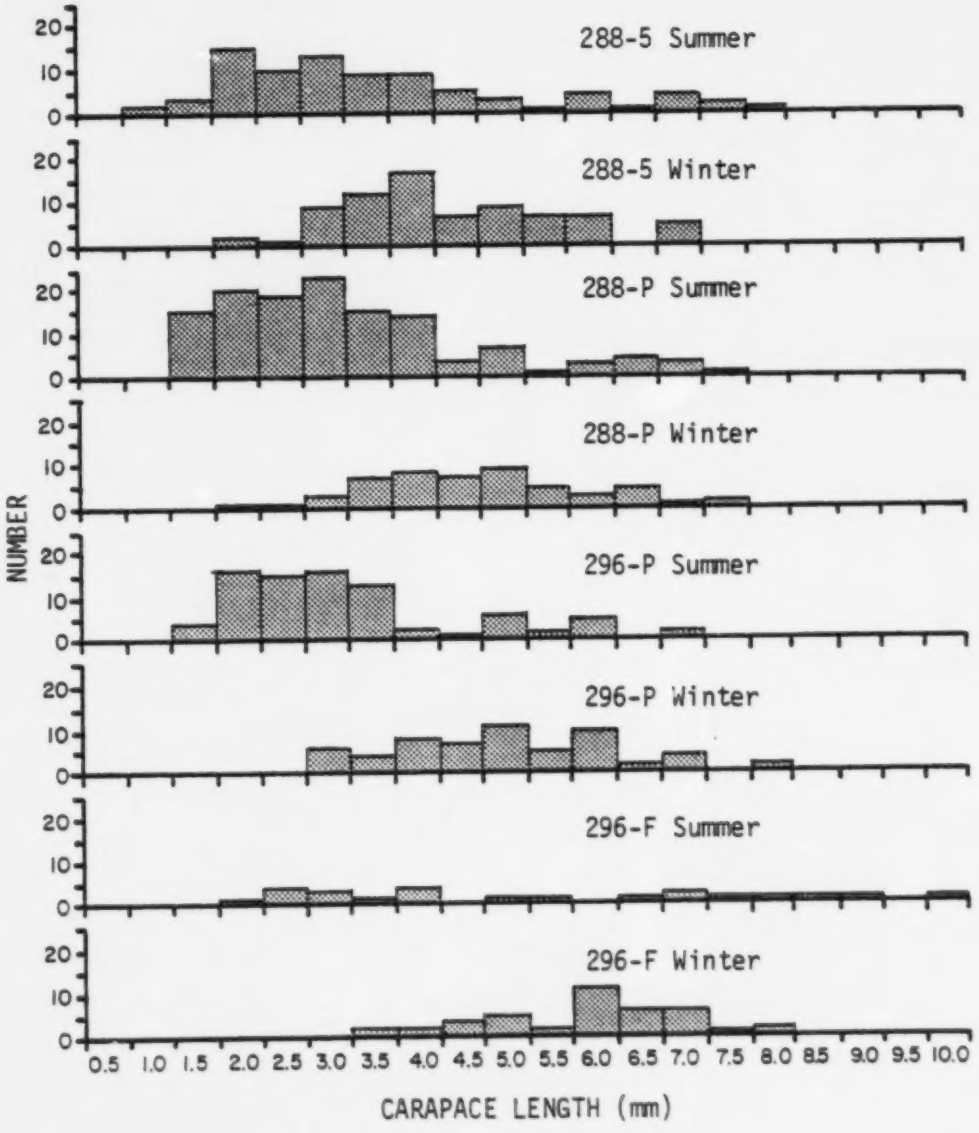


Fig. 8. Pistol shrimp length frequency histograms for stations 288-5, 288P, 296P, and 296F, summer 1978 and winter 1979. (3- and 8-m depths combined.)

Table 4. Results of ANOVA performed on summer and winter pistol shrimp abundance data for Buccaneer Oil Field, 1978-1979.

a. Summer

Source	DF	S.S.	M.S.	F
Total	77	16395.87		
Station	12	2420.93	201.74	1.16
Depth†	1	1475.96	1475.96	8.47*
Station x Depth	12	3441.66	286.81	1.65
Residual	52	9057.33	174.18	

*Significant at the 1% level

†Abundance greater at 8-m than at 3-m depth

b. Winter

Source	DF	S.S.	M.S.	F
Total	23	943.96		
Station	3	107.13	35.71	1.00
Depth†	1	247.04	247.04	6.90*
Station x Depth	3	17.13	5.71	0.16
Residual	16	572.67	35.79	

*Significant at the 1% level

† Abundance greater at 8-m than at 3-m depths

Stone Crab. This species was markedly more abundant in summer ($\bar{x}$ = 25/m^2) than during winter ($\bar{x}$ = 11/m^2, Table 3). Specimens collected during summer averaged 9.5 mm in carapace width (Range 3-29 mm, S.D. $\bar{x}$ = 7.3; SE $\bar{x}$ = 1.4) and specimens collected during winter averaged 20.7 mm in carapace width (Range 4-33 mm, S.D. $\bar{x}$ = 9.8, SE $\bar{x}$ = 2.4). Results of the ANOVAs performed on the respective stone crab abundance data for each season (Table 5) showed depth differences were significant. During the summer season, the stone crab was more abundant at 3-m depths than at 8-m depths and, no significant differences were observed during winter. However, more specimens were caught at 3-m stations than at 8-m stations during winter.

Although station abundance levels were not statistically significant, the distributional trend for stone crabs on production platforms during summer (Fig. 10) was of interest because of its marked similarity to the trends exhibited during the same season by both the total biomass of the fouling community (Fig. 5) and the abundance of live *B. tintinnabulum* (Fig. 6). The stone crab is dependent upon the biofouling community for both habitat and food. Of these, habitat is probably the limiting factor, particularly in terms of degree of relief or cover provided.

The relationship of stone crab density to that of pistol shrimp as derived from the 78 collections obtained from 3- and 8-m depths during summer 1978 when both species were abundant is shown by Fig. 11. With only a few outlying data points, the density of pistol shrimp declined in a curvilinear fashion as the density of stone crab increased. This and the other contrasts provided above provide evidence that biological interactions and/or density-dependent relationships likely have pronounced effects and must be taken into consideration when making the final effects assessment.

Brittle Star. As indicated by Table 3 and Fig. 12, well established brittle star populations were characteristic of only two BOF structures, Production Platform 288A and Satellite 288-5. As asexual reproduction is common for *Ophiactis* spp. (Barnes 1974) and brooding may be representative, the apparent lack of dispersal among structures in the field should not be surprising. This species bloomed in conjunction with the development of the fouling mat. During summer when fouling mat biomass ranged from an average of 0.7 to 3.0 kg/m^2, brittle star density averaged 771 individuals/m^2. In winter fouling mat biomass ranged from 3.3 to 10.7 kg/m^2; mean brittle star density (including all stations) was 5279/m^2.

Results of the ANOVAs (Table 6) showed significant differences among stations during both seasons and, during winter, significant depth and station x depth interactions. Significant differences in brittle star abundance during summer are summarized in Fig. 12. Results of the orthogonal contrasts of stations sampled during winter were:

Table 5. Results of ANOVA performed on summer and winter stone crab abundance data for the Buccaneer Oil Field, 1978-1979.

a. Summer

Source	DF	S.S.	M.S.	F
Total	77	323.79	4.21	
Station	12	45.79	3.82	1.51
Depth	1	118.15	118.15	46.78*
Station x Depth	12	28.51	2.38	
Residual	52	131.33	2.53	

*Significant at the 1% level

Stone crabs were more abundant at 3-m than at 8-m depths.

b. Winter

Source	DF	S.S.	M.S.	F
Total	23	24.50		
Station	3	4.83	1.61	1.55
Depth	1	1.50	1.50	1.44
Station x Depth	3	1.50	0.50	0.48
Residual	16	16.67	1.04	

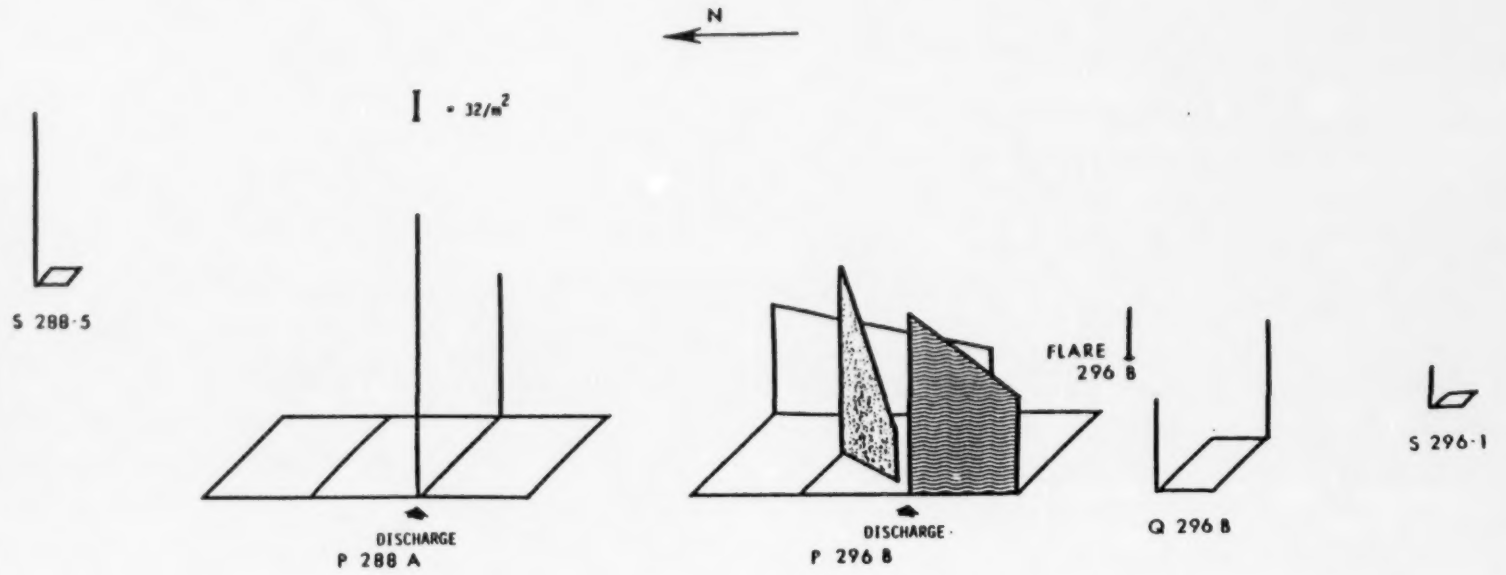


Fig. 9. Distributional patterns of the pistol shrimp among BOF structures, summer 1978.

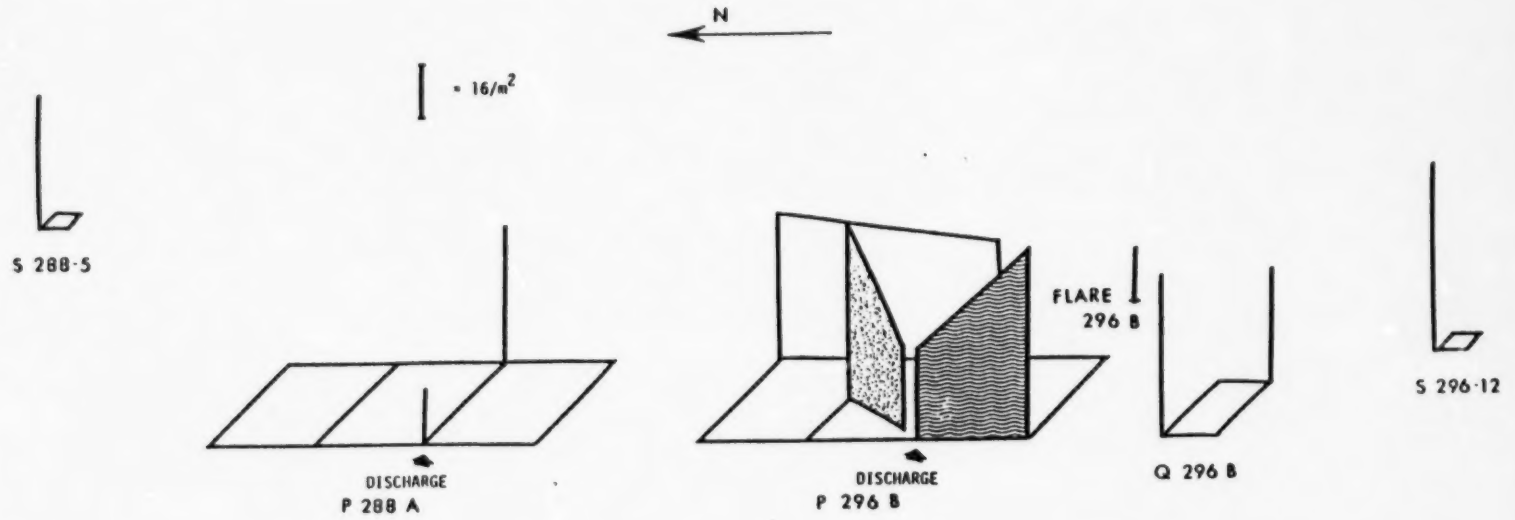


Fig. 10. Distributional patterns of the stone crab among BOF structures, summer 1978.

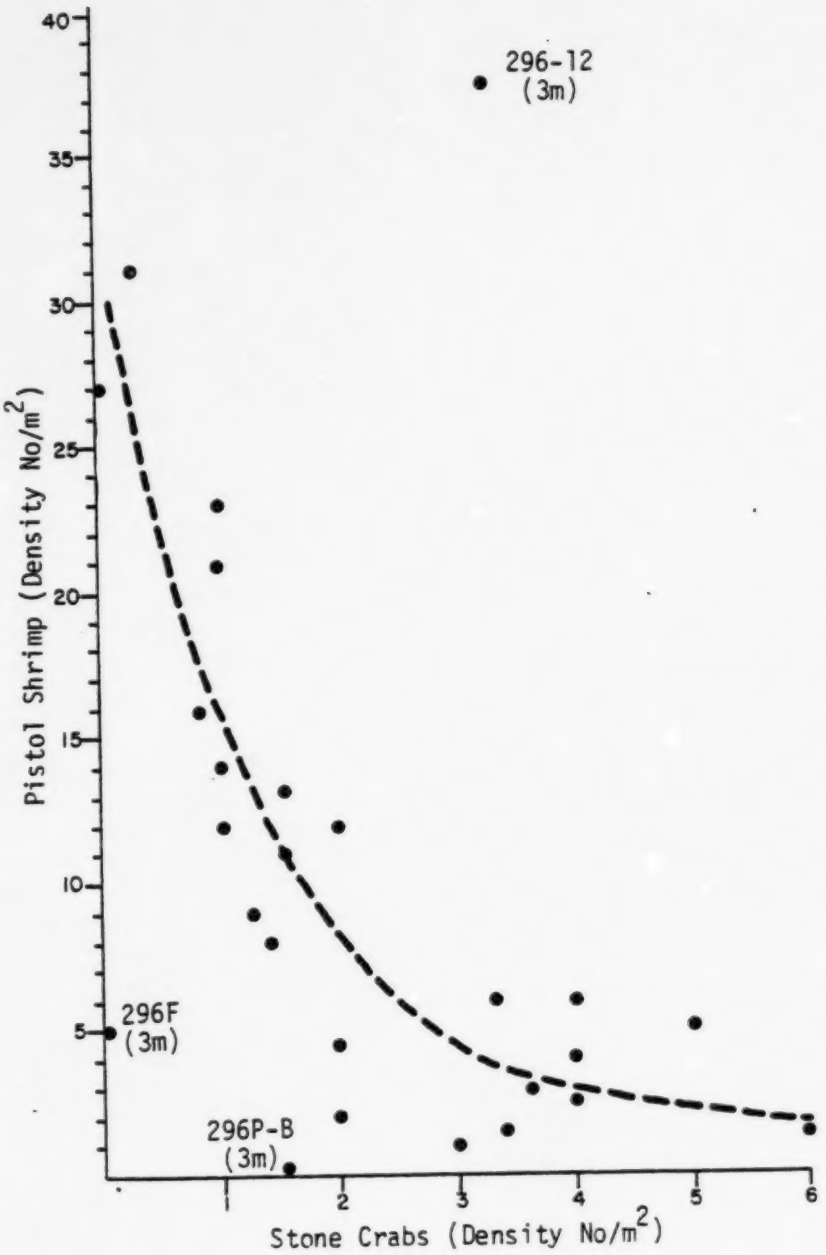


Fig. 11. Relationship of stone crab density to pistol shrimp density observed during summer 1978. (Each point represents the mean of three 0.0625/m^2 sample replicates.)

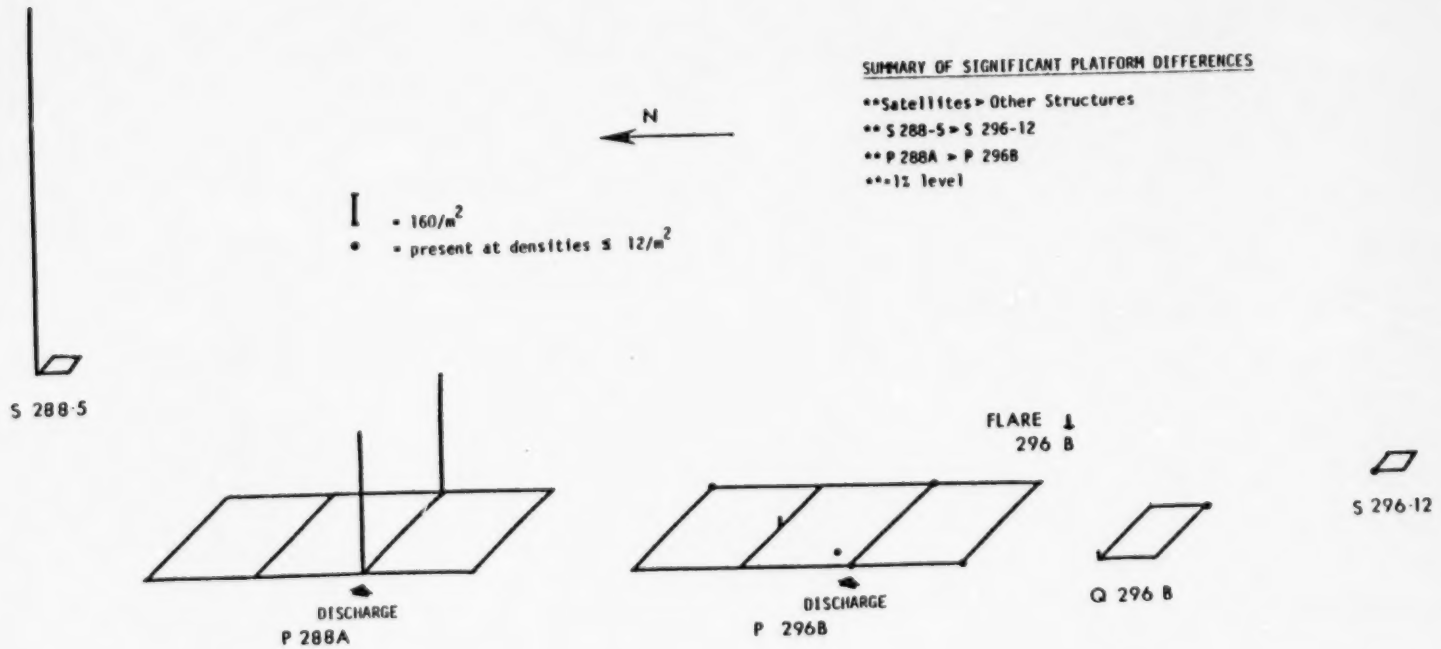


Fig. 12. Distributional patterns of the brittle star among BOF structures, summer 1978, with a summary of significant differences among stations based upon orthogonal contrasts.

Table 6. Results of ANOVA performed on summer and winter brittle star abundance data for the Buccaneer Oil Field, 1978-1979.

a. Summer

Source	DF	S.S.	M.S.	F
Total	17	172033.49		
Station	12	111653.15	9304.43	9.84**
Depth	1	265.85	265.85	0.28
Station x Depth	12	10928.49	910.71	0.96
Residual	52	49186.00	945.88	

**Significant at the 1% level.

b. Winter

Source	DF	S.S.	M.S.	F
Total	23	12343550.63		
Station	3	7677588.46	2559196.15	81.78**
Depth	1	996745.04	996745.04	31.85**
Station x Depth	3	3168497.13	1056165.71	33.75**
Residual	16	500720.00	31245.00	

**Significant at the 1% level.

Source	DF	M.S.	F
Control *vs* affected	1	7676015.01	32.9**
Productions *vs* Flare	1	393.36	0.00
Production 288A *vs* 296B	1	1180.08	0.01

**Significant at 1% level

Brittle stars at 288-5 were significantly more abundant at the 3-m depth (34,331/m^2) than at the 8-m depth (7675/m^2, Table 3). On Production Platform 288A, the density of brittle stars at the 3-m depth was 32/m^2 as opposed to 95/m^2 at the 8-m depth.

Flora

Species composition and biomass levels of various macroalgae contained in the summer and winter 1978-1979 harvest samples are shown by Tables 7 and 8, respectively. Of these species collected, two unidentified species of green algae (Nos. 2 and 3), *Bryopsis hypnoides* and red algae sp. 1 were observed only during winter while *Bryopsis plumosa*, *Polysiphonia* sp. 1 and *Ceramium byssoideum* were collected only during summer.

Most of the algae species represented were collected at both 3-m and 8-m depths. However, *Bryopsis plumosa* was collected only from 8-m depths and *Polysiphonia* sp.1, *Ceramium byssoideum*, and *Gelidium pusillum* were found only at a depth of 3-m (Tables 7 and 8). Summer biomass means of algae were 28.325 g/m^2 at 3-m depths and 6.354 g/m^2 at 8-m depths. During summer, the maximum algal biomass (66.592 g/m^2) was found at the 296 B flare at 3 m. In winter, algal biomass means were 5.891 g/m^2 and 1.08 g/m^2 at 3- and 8-m depths, respectively. Maximum density occurred at 296F (3 m) while the lowest value was found at 288PW (3 m) (Table 8). During winter algal densities at 3-m depths were higher at structures with no produced water discharge (288-5 and 296F) than structures with either previous and currently occasional discharges (288P), or with continuous produced water flows (296 PW).

The distribution of algae among stations was rather patchy even during the summer season of abundance. Only three species were observed at all stations; and 5 species were found at three or fewer stations. The greatest diversity (9 species) was at 296-12 while the lowest (5 species) was found at 296P (east leg). Green algae 1, *Polysiphonia subtilissima*, *Derbesia vaucheriaeformis* and *Callithamnion byssoides* were the biomass dominants during summer, and were most abundant at 3-m depths. The highest densities of green algae 1 were observed at 296P (discharge leg) and 296Q (heated water discharge leg). *Derbesia vaucheriaeformis* was most abundant at 296Pw and 296F; *Callithamnion byssoides* occurred in greatest densities at control structure 296-12 and 288-5. *Polysiphonia subtilissima* was found almost exclusively at 296F and 296-12.

Table 7. Algae biomass (g/m^2) by structure and depth in the Buccaneer Oil Field, summer 1978-1979.

Structure:	288-S		288-P		288-Pe		296-Pe		296-Pr		296-Qe		296-Qe		296-f		296-12		Total		
Depth:	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	Combined
Species																					
Chlorophyta																					
Derbesia marchantioides	0.474	0.006		1.248	3.578	0.160	20.479	0.006	0.685	2.298	0.640	0.256	0.967	1.408	18.464	0.698	0.943	0.006	46.228	6.086	52.314
Cladophora Sp. 1		1.446		0.978	0.006	2.054	0.006	4.640	9.120	0.006			6.669			1.709	0.006		15.807	10.783	26.590
Cladophora Sp. 2		0.006	7.070		0.006														7.084	0.006	7.090
Green Algae 1	0.032	0.006	1.170	0.006	3.504	0.006	20.486	4.640	9.600		28.096	0.192	6.713		9.517	0.339	3.034		83.040	5.189	88.229
Penicillus pluriramus												0.006		0.064						0.070	0.070
Rhodophyta																					
Galaxaura pacifica													0.006				0.006		0.569		0.569
Callithamnion byssoides	15.757	0.602	0.006	0.006	0.294	0.099	0.237		0.026				3.712	3.840	9.613	0.614	0.051	11.392	29.931	16.767	46.698
Polysiphonia denudata		0.019	0.006	1.971	0.774		0.006	0.006	0.006	0.218				0.006	5.734		0.250	0.006	6.674	14.494	21.162
Polysiphonia subtilissima		0.006			0.006		0.230	12.486						0.006	23.258	0.122	29.843	3.648	53.555	3.782	57.337
Polysiphonia Sp. 1					0.006												0.006		0.006		0.006
Ceramium byssiforme			0.006												0.006	0.006	12.013		0.006		0.006
Ceramium fastigiatum							0.006												12.025	0.006	12.031
TOTAL	16.263	2.085	8.274	4.159	8.254	2.309	41.450	21.778	19.437	2.522	30.430	0.466	18.067	5.324	66.592	3.488	46.150	15.052	254.925	57.183	312.102
# Species	3	7	5	5	8	4	7	5	5	3	5	5	5	5	8	6	9	4	11	9	12
	7		7		8		7		5		6		8		7		9			12	

Table 8. Algae biomass (g/m^2) by structure and depth in the Buccaneer Oil Field, winter 1978-1979.

Structure:	288-S		288-Pw		296-Pw		296-F		Total		
Depth:	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	3 m	8 m	Combined
Species											
Chlorophyta											
Derbesia vaucheriaeformis	0.006	0.026	0.115	0.928	0.448	1.363		0.608	0.569	2.925	3.494
Cladophora Sp. 1	0.006	0.166	0.006						0.012	0.166	0.178
Cladophora Sp. 2	0.006								0.006		0.006
Green Algae 1		0.013					1.510		1.510	0.013	0.013
Green Algae 2							2.138		2.138		1.510
Green Algae 3						0.019				0.019	2.138
Bryopsis hypnoides											0.019
Phaeophyta							7.168		7.168		7.168
Giffordia mitchelliae											
Rhodophyta							1.138		1.138		1.138
Gelidium pusillum	8.506	0.070	0.006		1.843	0.454	0.474		10.829	0.524	11.353
Callithamnion byssoides					0.192				0.192		0.192
Polysiphonia denudata		0.013								0.013	0.013
Polysiphonia subtilissima		0.659						0.006		0.665	0.665
Red Algae 1											
TOTAL	8.524	0.947	0.127	0.928	2.483	1.836	12.428	0.614	23.562	4.325	27.887
# Species	4	6	3	1	3	3	5	2	9	7	13
	7		3		4		7		13		

Pipeline Biomass

Total fouling community biomass on the pipeline during summer and winter was 0.75 and 0.05 kg/m^2, respectively. These values compared to 0.21 and 0.17 kg/m^2 on the platform leg during each of the respective seasons at a similar depth. The summer sample from the pipeline contained barnacles which probably accounts for most of the discrepancy. Also, the winter samples are suspect since we were attempting to sample in water conditions of extremely low visibility.

Macroalgae were reasonably well-represented at each of the deep (≈ 21 m) stations sampled during summer:

Species	Pipeline (g/m^2)	Platform leg (g/m^2)
Bryopsis hypnoides	5.184	7.955
Cladophora sp. 1	0.800	0.006
Derbesia vaucheriaformis	0.006	0.269
Green algae sp. 1	0.826	0.006
Polysiphonia denudata	0.006	-
Total	6.822	8.236

Each collection was dominated by *Bryopsis hynoides*, a species not represented among the 3- and 8-m deep stations in summer. During winter, a single species (*Callithamnion byssoides*) was represented at the deep stations (only on the pipeline, 0.003 g).

Recolonization

Due to a late start on the contract and weather-related problems, the recolonization experiments were performed on a slightly different schedule than originally planned (Fig. 13). The main difference was that the spring-summer, 90-d recolonization samples extended for a longer period than planned, more resembling the initial 180-d sample in terms of total recolonization period than the other "90-d" experiments. However, the spring-summer 180-d experiment was initiated several weeks earlier than the "90-d" experiment, a factor which will be shown below to have made a major difference in the results.

Results of the ANOVA's performed on the total biomass data (g/m^2/d) for the 90-d-surface, 180-d-surface and the 90-d-surface to 8-m deep recolonization experiments are shown by Tables 9 and 10. Results from the "90-d" surface experiments yielded significant differences for each factor considered and their interactions, whereas the results from the "180-d" surface experiment showed both structure and season to have been significantly different (Table 9). All factors and all interaction terms were significantly different for the expanded recolonization experiment (Table 10).

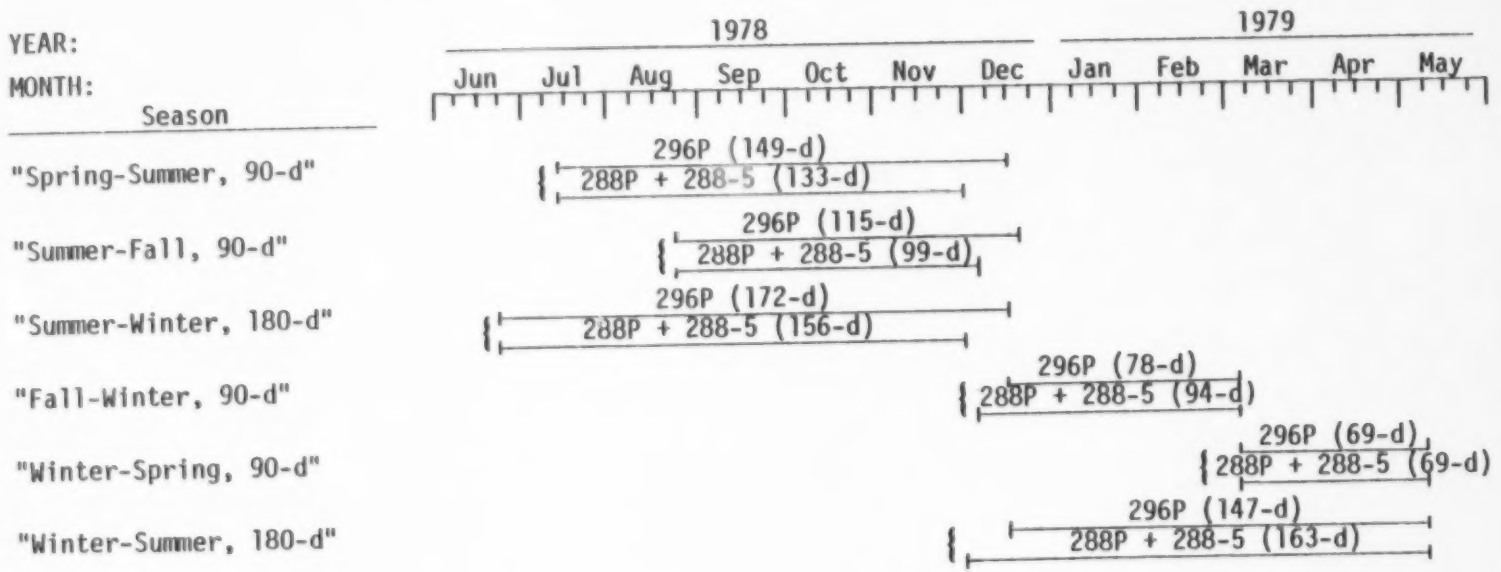


Fig. 13. Schedule for recolonization experiments performed in the Buccaneer Oil Field, 1978-1979.

Table 9. Results of ANOVA performed on total biomass data ($g/m^2/d$) for surface recolonization samples collected seasonally in the Buccaneer Oil Field, 1978-1979.

a. 90-d Surface

Source	DF	S.S.	M.S.	F
Total	35	11902.58		
Structure	2	1950.95	975.48	19.53**
Season	3	4367.58	1455.86	29.15**
Structure x Season	6	4385.42	730.90	14.63**
Residual	24	1198.63	49.94	

b. 180-d Surface

Source	DF	S.S.	M.S.	F
Total	17	28893.65		
Structure	2	4137.53	2068.77	4.18*
Season	1	16226.40	16226.40	32.75**
Structure x Season	2	2583.99	1291.99	2.61
Residual	12	5946.14	495.51	

* Significant at the 5% level

**Significant at the 1% level

Table 10. Results of ANOVA performed on total biomass data ($g/m^2/d$) for recolonization samples taken seasonally at the surface, 3-, 5- and 8-m deep stations on Production Platform 296B and Satellite 288-5, 1978-1979.

Source	DF	S.S.	M.S.	F
Total	95	31408.11		
Structure	1	937.19	937.19	15.19**
Depth	3	1913.35	637.78	10.34**
Season	3	9185.59	3061.86	49.64**
Structure x Depth	3	3771.39	1257.13	20.38**
Structure x Season	3	3328.24	1109.41	17.99**
Season x Depth	9	2523.73	280.41	4.55**
Structure x Depth x Season	9	5800.83	644.54	10.45**
Residual	64	3947.77	61.68	

**Significant at the 1% level

A summary of the means of the recolonization data which were subjected to ANOVA is presented by station, depth and season in Fig. 14. Recolonization at surface stations beneath produced water discharges (particularly production platform 296B) were markedly lower than the rates at 288-5 for the first two 90-d experiments and for the initial 180-d experiments. Although total period for recolonization between the 90-d and 180-d experiments was not pronounced (Fig. 13), biomass produced in the latter experiment initiated in June was much higher than that resulting from the 90-d experiment initiated in July. Most of the biomass in these samples was represented by *B. amphitrite*. This species probably spawns throughout the warm season, but peak spawning occurs during late spring.

The December-February "90-d" period, was characterized by surface recolonization rates ($g/m^2/d$) similar to those observed for the proceeding periods, but abundance of barnacles in the samples was low and biomass at the surface beneath the produced water on 296B was markedly higher than that observed at other surface stations. Very little recolonization occurred at any of the surface stations during the February-May period. However, as evidenced by their particularly small size, a barnacle set did occur late in this period

Surface recolonization rates were low for the 180-d, winter-to-summer recolonization experiment (Fig. 14). The highest rate was at 288P, 288-5 was characterized by an intermediate rate, and 296P was characterized by lowest production. The experiments for 288-P and 288-5 were initiated in November and the samples contained barnacles whereas the experiment at 296P was initiated in December and contained no barnacles. In contrast to other seasons when *B. amphitrite* dominated, *B. tintinnabulum* dominated the collections taken at 288P and 288-5 during the winter-summer sampling period.

The results of the Duncan's Multiple Range tests comparing surface stations for both the 90- and 180-d experiments were similar:

a. 90-day Surface Experiment (N = 12, α = 0.05, DF = 24)

Structure	288-5	296P	288P
*$\bar{x}$ *$g/m^2/d$)	28.7	13.7	12.6

b. 180-day Surface Experiment (N = 6, α = 0.05, DF = 12)

Structure	288.5	288P	296P
$\bar{x}$ ($g/m^2/d$)	53.4	50.5	19.9

*Means underscored by the same line are not significantly different

In each case, 288-5 was characterized by the highest biomass level. In the 90-d experiment the biomass level at 288-5 was significantly higher than biomass levels at the two production platforms. In the 180-d experiment, biomass levels at Production Platform 296B was significantly

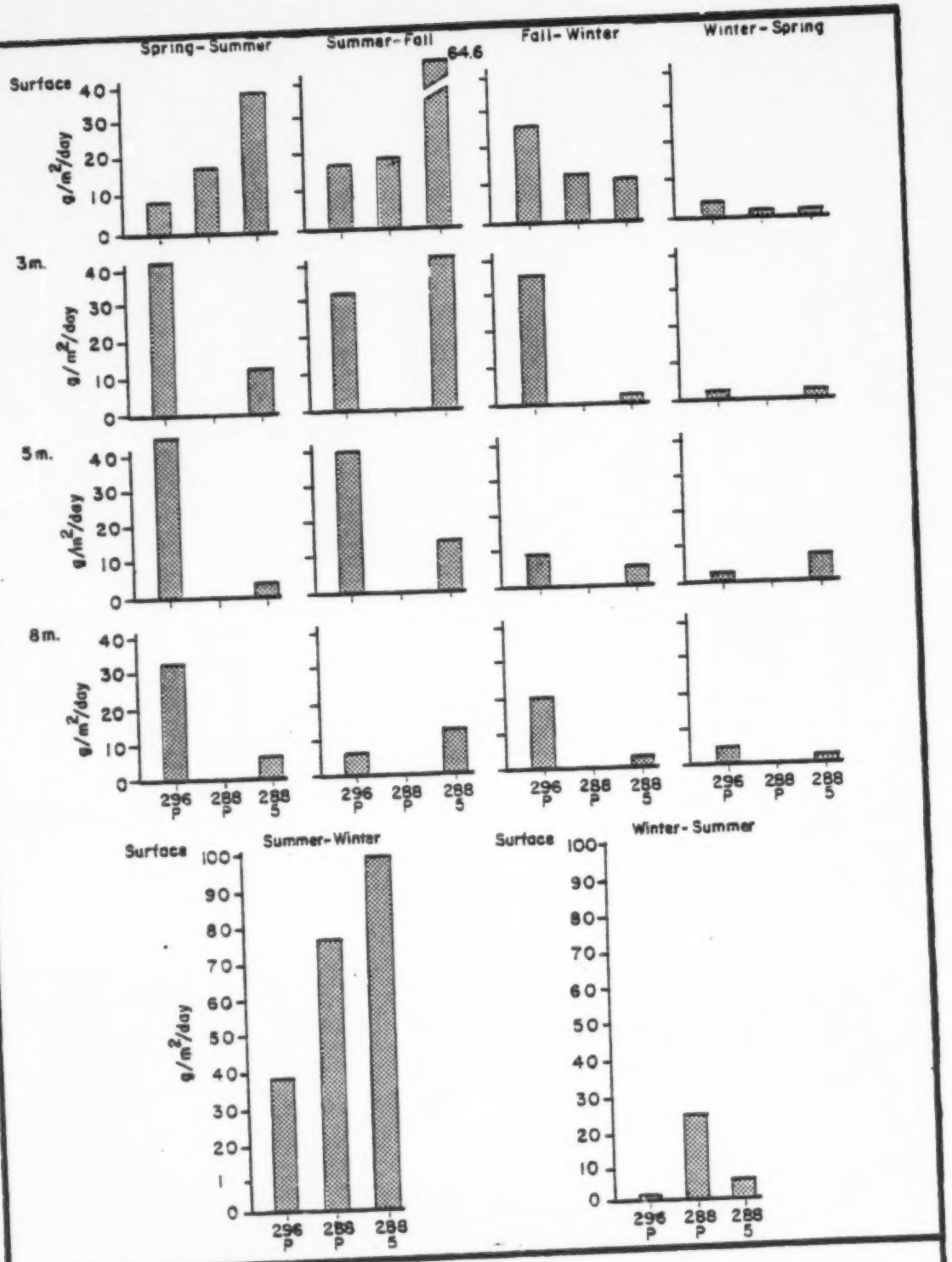


Fig. 14. Recolonization biomass produced on BOF structures 1978 - 1979.

lower than biomass at either of the controls (288-5, highest) or the intermittently discharging platform (288P).

However, when recolonization throughout the water column to a depth of 8 m is considered (Fig. 14), mean biomass level resulting from recolonization of cleaned substrates at Production Platform 296B ($\bar{X}$ = 20.4 $g/m^2/d$) was significantly higher (5% level) than that at 288-5 ($\bar{X}$ = 14.2 $g/m^2/d$). Most of the differences were attributable to sets of *B. amphitrite* at depths on 296B but not at 288-5. The detrimental effects of produced water on recolonization rates appear restricted to depths of less than 3 m.

Condition of *B. tintinnabulum*

Based upon a total of 180 barnacles comprising the condition sample, there was a significant (1% level) regression of meat dry weight on cavity volume (F = 75.8 at 1 and 178 DF). The results of the general linear models procedure we used to compare regressions of meat dry weight to sources of variation were:

Source	DF	S.S.	M.S.	F
Total	179	35.63079		
Cavity Volume	1	10.6436	10.6436	106.19**
Season	5	7.0919	1.4184	14.15**
Cavity Volume x Season	5	1.0567	0.2113	2.11
Residual	168	16.8387	0.1002	

**Significant at the 1% level

The lack of significant meat weight by cavity volume by season interaction difference indicates that each of the seasonal meat weight to cavity volume regressions could be considered as a series of parallel regressions (non-significant slope differences) as opposed to a series of regressions having significantly different slopes.

The comparison of predicted seasonal dry weight of meat at the adjusted mean cavity volume was made using Duncan's Multiple Range test. The results were:

Season	Sp	Su	W	F	F	F
Structure/ Depth (m)	296Q/(1)	296Q/(8)	296Q/(1)	296P/(1)	296Q/(1)	296Q/(8)
*$\bar{w}$,($\bar{X}e^{X}$) (N=30)	0.94	0.63	0.63	0.60	0.57	0.45

*Means underscored by the same line are not significantly different at the 5% level.

The purpose of this years barnacle condition experiments was not only to evaluate seasonal differences as indexed by regressions of meat weight to cavity volume on a log scale, but even more importantly, to also determine if the derived index would be sensitive enough to reflect significant differences. The summer data were encouraging in that the relationship of meat to cavity volume was linear in spite of the differences in morphotypes of large *B. tintinnabulum* . These results led to the expanded collections made in fall, the results of which indicated that condition levels varied little among the structures sampled but that barnacles at 1-m depths appeared in better condition than those at 8-m depths. Given these results, subsequent collections made in winter and spring were made at 1-m depths. In summary of the seasonal results, condition of *B. tintinnabulum* appeared highest during May (which was either prior to,or early in,the estimated spawning period) than during other seasons. Condition of this species at 8-m depths on the quarters 296B platform during the summer spawning period (August) was higher than condition of barnacles taken from that station after the spawning season (December).

Next years (1979-1980) experiment will be specifically designed to evaluate effects of the produced water discharge. Comparisons will be made using samples taken within a single season and at a consistent depth.

Toxicity Observations

The above data indicate that areas beneath produced water discharges exhibit measurable effects over a limited area. During the 1979-1980 program, the areal extent of observed effects will be related to the toxicity of effluent using the results of the hydrographic and bioassay work units in conjunction with our field data describing distribution and abundance. Mean 96-h LC50 effluent concentrations determined by Work Unit 2.3.4 during 1978-1979 showed crustaceans were more sensitive to the effluent than fish:

Organism	Concentration (ppm) $\bar{x}$ 96-h LC50	$\bar{x}$ 48-h LC50	Concentration (%)
Larval brown shrimp		9500	0.95
Subadult white shrimp	68,000	-	6.8
Adult white shrimp	70,000	-	7.0
Barnacle	83,000	-	8.3
Subadult brown shrimp	100,000	-	10.0
Adult brown shrimp	116,000	-	11.0
Crested blenny	269,000	-	26.9

To supplement the above data, we performed a simple bioassay on a representative, cryptic crustacean (the amphipod *Jassa falcata*) in March of 1979. A sample of 20 amphipods were placed in quadruplicate

in seawater, and in 1 and 10% produced water-seawater solutions, respectively. These were maintained at 17 C for 48 h. Mortalities in the 10% treatments after 2, 12, 24 and 48 h were 12.5, 58.8, 75.0 and 100%, respectively. Respective mortalities in the 1% solutions were 0, 0, 12.5 and 12.5%. None of the control organisms died.

Feeding of *B. tintinnabulum*

During August, feeding activity as determined by diver observations every 4 h, showed that barnacles were most active at night (Fig. 15). During the period of darkness, greater than 85% of the barnacles observed exhibited cirral movement. During daytime, diurnal activity was observed in less than 10% of the barnacles.

Time-lapse photography was performed on a cluster of barnacles (*Balanus tintinnabulum*) over a 24-h time span during the December sampling period. The product resulting from the time-lapse system was a super-8 movie record of epifaunal activity over an entire daily cycle. Individual barnacles were observed for cirral and opercular movements. The time of day was derived from the number of movie frames elapsed after the initiation of the 24-h cycle. Correlation of the movie to actual time of day was within 1% of the total period. The complete extension of cirri was designated to represent feeding activity (Crisp and Southward 1961).

The period of observation started at 1446 h on 18 December 1978. Partial opening of the opercular valves occurred around 1700 h. The first heavy cirral activity was observed around 1800 h or 6:00 pm, which closely corresponded to sunset. Intense cirral movements continued until around 0630 h which was within 15 minutes of sunrise. No cirral activity was recorded after this time. After daylight period started, the only behavior which could be detected was movement of the nearly closed opercular structures.. This activity also represents a variety of feeding but at a much different level and efficiency than captorial feeding by extension of the cirri (Crisp and Southward 1961).

Observations were made *in situ* during this same 24-h interval in December. As before, divers recorded numbers of barnacles exhibiting cirral extension over the diurnal cycle and the results were similar to those obtained above; greatest feeding activity occurred at night (Fig. 15).

During summer, fecal pellet production occurred within the 4-h holding period used for the experiment. Wet weights of produced pellets ranged from 0.0 to 26.1 mg/5 barnacles throughout the 24-h period. An index using the ratio of fecal pellet weight to barnacle flesh weights multiplied by 1,000 was calculated to represent production of feces during this period. As depicted in Fig. 15, fecal pellet production was closely correlated with feeding activity during summer.

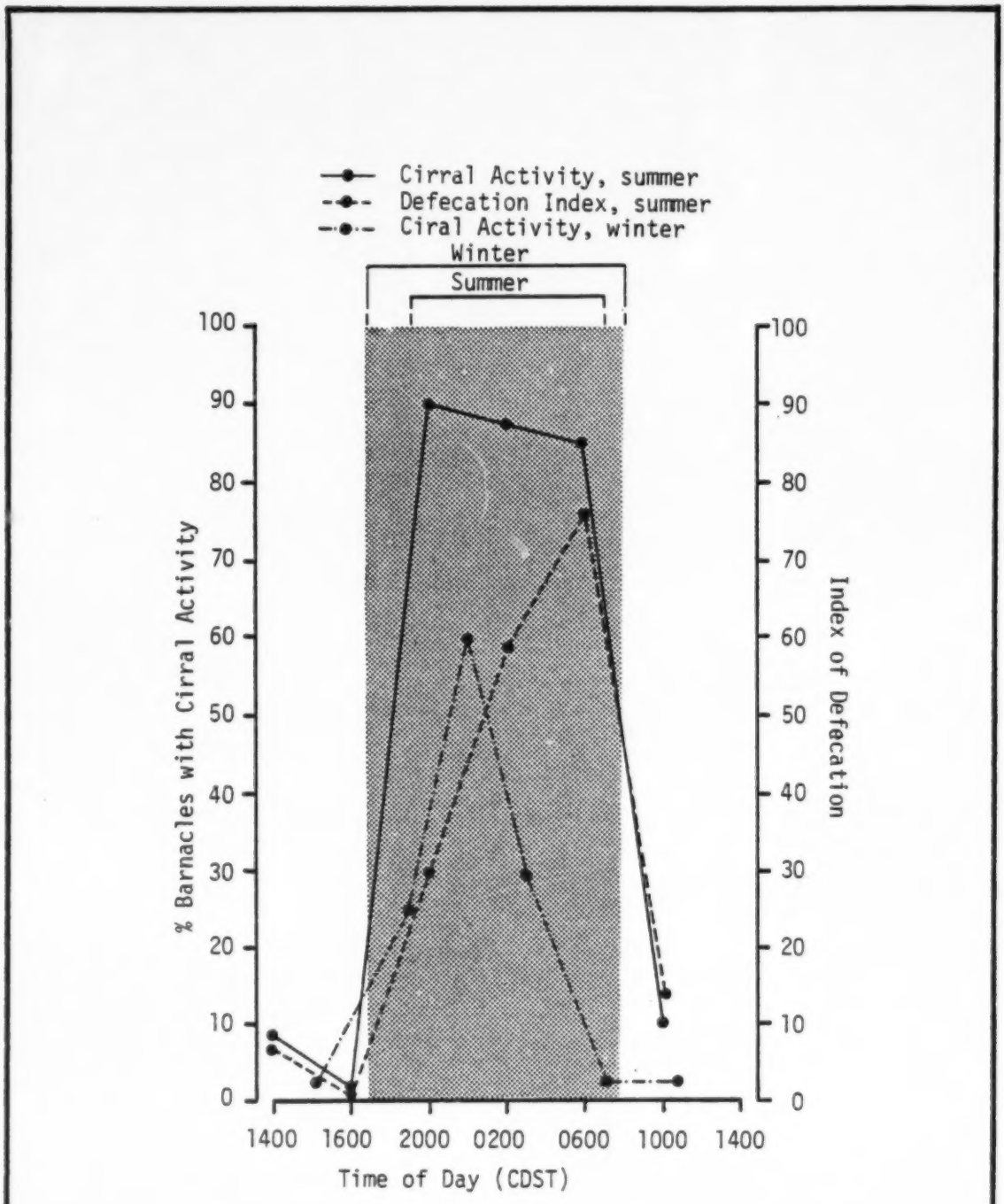


Fig. 15. Diurnal activity of *Balanus tintinnabulum*, 18-19 August 1978. (Shaded area represents period of darkness.)

During winter, no fecal pellets were produced. If experimental errors were not involved, this indicates that 1) ingestion rates were greatly reduced during the colder part of the year, 2) assimilation is extremely high in winter, 3) little food was available, or 4) a combination of all of the above.

Production of the Small Barnacle, *B. amphitrite*

Production ($\Sigma\Delta P$) of a single recruitment of *B. amphitrite* was calculated to be 9.3 $g/m^2/d$ (Table 11). Seasonal production increments (ΔP) were highest during the initial growth phase and gradually decreased with time. As expected, the mean weight ($\bar{w}$) of individuals increased with time while the total number of individuals (N) decreased. The instantaneous standing crop ($N\bar{w}$) remained relatively constant from November to May due to increased size and decreased number of individuals. The principle causes of mortality appeared to be crowding and overgrowing of the original barnacle recruitment by subsequent growths of *B. amphitrite* and *B. tintinnabulum*. Observation and comparisons of nearby adult barnacles prior to the collection in May indicated this species reaches maturity in less than 1 yr.

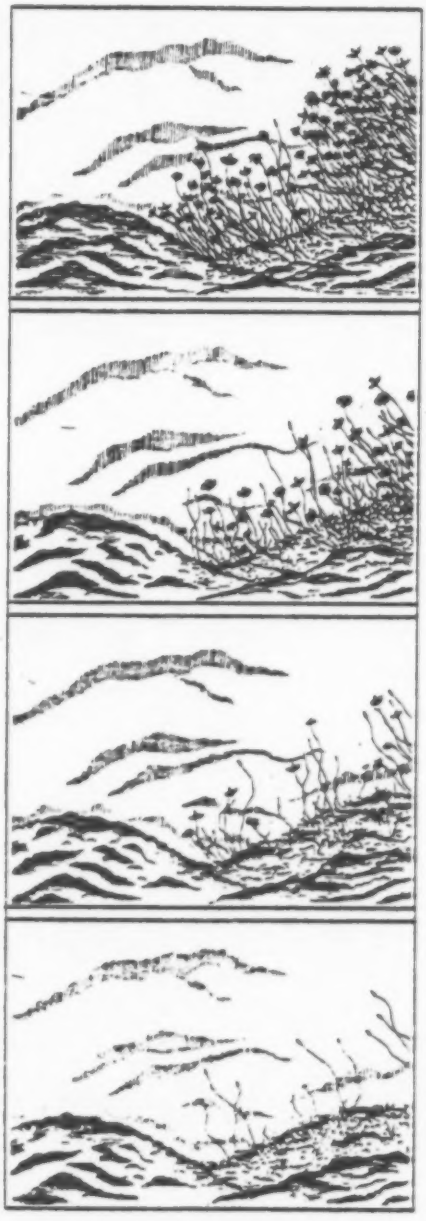
Production of the Hydroid, *Tubularia crocea*

Planktonic larvae of this species of hydroid settle only on clean substrates with reproduction apparently beginning in fall and extending through early spring. A colony develops quickly with a clean substrate becoming covered by the basal (or holdfast) part of the colony, and stalks are extended. Clean substrate is typically provided by either new, unfouled barnacle shells or by fresh scars on the structure resulting from large clumps of barnacles breaking-off the platform. Each stalk is tipped with tentacles which serve to capture prey.

Colonies which develop near the surface (1 to 2 m) appear more robust than colonies which establish at greater depths, and near-surface colonies persist for a longer period of time than those at greater depths. For example, a colony approximately 8 m deep monitored over the period 1-28 March 1979 using time-lapse photography visibly declined (Fig. 16). While the 8-m deep colony was in an active state of decline, colonies being monitored and sampled near the surface continued to flourish. All colonies had declined by late April. During all but the fall to spring period when colonies flourish, this species is represented by only a few, scattered stalks which are difficult to locate during other seasons.

We have never observed spadefish to graze on hydroid colonies; but, during the period of hydroid decline, the entire digestive tract of spadefish is often packed with *T. crocea*. We believe the hydroid material sloughed from the platform provides a seasonally important food

HYDROID TIME LAPSE PHOTOGRAPHY



Week 1, March 1979
Healthy colony
1 March 1979

Week 2, March 1979
Colonial biomass decline has occurred

Week 3, March 1979
Degradation progressing

Week 4, March 1979
30 days elapsed
Nearly complete degradation

Fig. 16. Artistic representation of the spring decline of a hydroid colony at 8-m depth on 296Q, as indicated by time-lapse photography.

Table 11. Small barnacle production measurements.

Harvest Date	Δt (days)	Mean Individual wt $\bar{w}$ (g)	Total No. Per .0625 m^2 N	Standing Crop $N\bar{w}$ (g)	Avg Value N	Avg Mean Wt	$\Delta\bar{w}$	ΔP	$\Sigma\Delta P$ (g)
14 July 1978 (area cleared)	0	0.005*	300	1.50	-	-	-	-	-
15 Nov 1978	134	0.447	133	59.50	217	0.226	0.442	95.91	95.91
6 Mar 1979	101	0.968	67	64.87	100	0.708	0.521	52.1	148.01
16 May 1979	71	1.551	36	55.83	52	1.26	0.581	30.2	178.21†

†178.21 g : 0.0625 m^2 = 2,851 g/m^2 ÷ 306 d = 9.3 $g/m^2/d$

*estimated value

item during early spring when other foods for spadefish are not abundant. Further, amphipods and other small crustaceans, important foods of small reef fish, are apparently able to seasonally flourish in the hydroid colonies. The timing of the hydroid decline corresponds to the period of annual recruitment of reef fish to the platforms. Prey density (amphipods, etc.) at this time may exceed the available cover, rendering them susceptible to predation. The dominant bryozoan (*B. neritina*) discussed below has a similar pattern of seasonal abundance and, although we have not found it to be an important food of any fish species, it probably plays an ecological role similar to that indicated for *T. crocea*.

At the time of the initial clippings individual hydroid stalks ranged from about 16- to 29-mm long, averaging 23 mm in length. The average stalk weighed 0.007 g (N=40). Following the 23-d interval, stalks from the previously clipped area averaged about 13 mm long indicating a growth rate of 0.55 mm/d. Stalks from the undisturbed portion of the colony averaged 35-mm long for a growth rate of 0.53 mm/d. The maximum observed length attained by any stalk was 50 mm. At the end of the experiment, the average 13-mm long, new stalk weighed 0.00375 g, indicating a biomass increase of 0.00016 g/d. In contrast, the average undisturbed stalk weighed 0.017 g indicating a biomass increase of 0.00042 g/d.

Similar sized whole colonies (visual estimates) were collected at the initiation and end of the experiment for the purpose of evaluating the production estimates. One colony of 500 stalks collected on 13 March did approximate one of the colonies collected on 5 April 1979 (480 stalks). The colony collected 13 March weighed 15.6 g. Assuming no predation and using the above rate of daily biomass increase, a colony of this size would be predicted to weigh 20.4 g (15.6 + [0.00042 g/stalk/d x 500 stalks x 23 d]). The 480-stalk colony collected on 5 April had a total weight of 19.4 g. The growth estimates appear reasonable.

The lines used in establishing the belt transects to measure bryozoan production were colonized by *T. crocea* during the period 6 March to 16 May 1980. The density was 1.7 stalks/cm^2 of exposed line surface. Stalk lengths ranged from 6 to 24 mm in length and averaged 18-mm long. The stalks averaged 0.0041 g in weight. The daily increase in length of a stalk was estimated at 0.29 mm whereas biomass increased at a rate of 0.00007 g/day. Colonies establishing late in the season had slower growth rates than that observed for established colonies during the same period.

Production of the Bryozoan, *Bugula neritina*

Transects from which *B. neritina* were removed on 6 March 1980 colonized slowly over the sampling period. Following 63- to 71-d of growth, the resulting collections indicated a net production of 0.00024 g/cm^2/d or 2.4 g/m^2/d. These values correspond well with the production values for this period which can be obtained from the recolonization sampling effort (Fig. 14).

CONCLUSIONS AND SIGNIFICANT FINDINGS

The ultimate goal of our research in the BOF has been to obtain the information and data necessary to provide a comprehensive impact assessment during the final year of study. Each year's research plan has been guided by the findings of the previous year's study. In this manner, our research program has evolved from a general inventory to a series of field experiments designed to fill specific data gaps. The significant findings of this year's program which have not been reported in previous year's research were:

- Production Platform 296B was estimated to have discharged 5.08×10^5 bbl of produced water during 1978-1979.
- Results from respirometry experiments indicated that biofouling primary production rates were low and that produced water generally increased the oxygen demand of the systems under study, particularly the biofouling components.
- A well casing on Production Platform 296B had lower biomass than other platform supports, measurable effects on total biomass from produced water were limited to near the area of the discharge point.
- Pistol shrimp were significantly more abundant at 8-m depths that at 3-m depths during both summer and winter, and were slightly more abundant in summer than winter.
- Stone crabs were significantly more abundant at 3-m depths than at 8 m and were more abundant in summer than in winter.
- Brittle stars were patchily distributed and were most abundant at Satellite 288-5. Maximum densities were at 3-m depths.
- Biomass of macroalgae was higher in summer (28 g/m^2 at 3 m; 6 g/m^2 at 8 m) than in winter (6 g/m^2 at 3 m; 1.0 g/m^2 at 8 m) and higher at 3-m depths than at 8-m depths.
- The macroalgae were dominated by greens and reds, distribution by species was patchy during both seasons and exhibited few definite trends.
- During winter, structures without discharges had higher macroalgae biomass at 3-m depths than structures with discharges.

- Recolonization samples taken for summer and fall seasons were dominated by *Balanus amphitrite*. Beneath the discharge, numbers and biomass increased with depth, whereas abundance and biomass decreased with depth at control structures.

- Recolonization rates were low for winter and spring seasons.

- Long-term recolonization experiments performed at the surface for summer to winter and winter to summer periods gave results similar to the short-term seasonal experiments. In general, lowest biomass was obtained at production platforms and highest biomass at control structures.

- *B. tintinnabulum* condition was intermediate in summer, lowest in fall and increased from the fall low to a spring high. The differences were mostly associated with reproduction stages.

- Barnacles at 1-m depths were characterized by significantly better condition than those living at 8-m depths.

- Comparisons of the production discharge leg to a quarters platform leg using condition of barnacles from 1-m deep collections as the response variable showed no significant differences.

- A 10% solution of produced water-seawater killed 100% of the amphipod *J. falcata* in 48 h; a 1% solution killed 12.5% in 48 h.

- The large barnacle, *Balanus tintinnabulum*, feeds during the night with feeding rates apparently higher in summer than in winter.

- Barnacle production experiments indicated production rates for a single recruitment of *B. amphitrite* was 9.3 $g/m^2/d$ and that adult size is attained in 1 yr.

- Production experiments using the hydroid, *Tubularia crocea* as a test animal, indicated that winter production rates for an average stalk was 0.00016 g/d for areas undergoing regrowth after clipping, and 0.00042 g/d for undamaged areas of the colony.

- Based upon the above results and those from time-lapse photography, hydroid production is high during winter and the colonies decline markedly during spring.

- Production rate of the bryozoan *Bugula neritina* during a winter to spring period was estimated to have been 0.24 mg/cm^2/d.

The above results have generally verified our previous findings and have filled most of the data gaps needed for the impact assessment. Field work which is needed during 1979-1980 includes the collection of more barnacle samples for condition comparisons. These data will be used to compare structures with produced water discharges to control structures.

LITERATURE CITED

Barnes, R.D. 1974. Invertebrate zoology. Third edition, W.B. Saunders Co., Philadelphia, Pennsylvania. 870 p.

Brooks, J.M., E.L. Estes and W.H. Huang. 1980. Investigations of surficial sediments and suspended particulates at Buccaneer Field. Vol. 2. *In*: W.B. Jackson and P. Wilkens (eds.), Environmental assessment of an active oil field in the northwestern Gulf of Mexico 1978-1979. Chemical and physical investigations. NOAA Annual Report to EPA. Project Number EPA-IAG-DS-E693-EO. NOAA.

Crisp, D.J. 1971. Energy flow measurements. Pages 197-279. *In*: Holme, N.A. and A.D. McIntyre (eds.), Methods for the study of marine benthos. IBP Handbook No. 1b. Blackwell Scientific Publications. Oxford. 334 p.

Crisp, D.J., and A.J. Southward. 1961. Different types of cirral activity of barnacles. Phil. Trans. Roy. Soc. London. Ser. B. Biol. Sci. 243(705):271-308.

Fotheringham, N. 1977. Effects of offshore oil field structures on their biotic environment: benthos and plankton. Pages 487-550. *In*: W.B. Jackson (ed.), Environmental assessment of an active oil field in the northwestern Gulf of Mexico 1976-1977. NOAA Annual Report to EPA. Project Number EPA-IAG-DS-E693-EO, NOAA, NTIS Accession No. PB283890.

Gallaway, B.J., R. Howard, K. Green, and L. Martin. 1976. A study plan for the Buccaneer Oil Field assessment program. Report to National Marine Fisheries Service, Gulf Fishery Laboratory, Galveston, Texas. LGL Limited-U.S., Inc., Bryan, Texas. 69 p.

Gallaway, B.J. and F.J. Margraf. 1978. Simulation modeling of biological communities associated with a production platform in the Buccaneer oil and gas field. Annual report to National Marine Fisheries Service, Galveston, Texas. LGL Limited-U.S., Inc., Bryan, Texas. 58 p.

Gallaway, B.J., M.F. Johnson, R.L. Howard, L.R. Martin, and G.S. Boland. 1979a. A study of the effects of Buccaneer oil field structures and associated effluents on biofouling communities and the Atlantic spadefish (*Chaetodipterus faber*). *In:* W.B. Jackson (ed.), Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1977-1978. Volume II: Data Management and Biological Investigations. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO. NOAA, NTIS Accession No. PB 80165970.

Gallaway, B.J., M.F. Johnson, G.S. Boland, G.S. Lewbel, L.R. Martin, F.J. Margraf, and R.L. Howard. 1979b. The artificial reef studies. *In:* Ecological investigations of petroleum production platforms in the central Gulf of Mexico. Final report to Southwest Research Institute for the Bureau of Land Management. Washington, D.C. 108 p. + appendices.

Gallaway, B.J. and L.R. Martin. 1980. Pelagic, reef, and demersal fishes and macrocrustaceans. Vol. 4. *In:* W.B. Jackson and P. Wilkens (eds.), Environmental assessment of an active oil field in the northwestern Gulf of Mexico. Biological investigations. NOAA Annual Report to EPA, Project Number EPA-IAG-DS-E693-EO. NOAA.

George, R.Y. and P.J. Thomas. 1974. Aspects of fouling on offshore oil platforms in the Louisiana shelf in relation to environmental impact. Final report, Offshore Ecology Investigations, Gulf Universities Research Consortium. 54 p.

Gunter, G. and R.A. Geyer. 1955. Studies of the fouling organisms of the northwestern Gulf of Mexico. Publ. Inst. Mar. Sci. Univ. Tex. 4: 37-67.

Humm, H.J. undated. The effect of offshore oil and gas wells on the benthic marine plants of Louisiana. Final report, Offshore Ecology Investigations, Gulf Universities Research Consortium. 20 p.

Jackson, W.B. (Editor). 1977. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1976-1977. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO, NOAA, NTIS Accession No. PB283890. 759 p.

Jackson, W.B. (Editor). 1979a. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1977-1978. Volume I: Synopsis. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO. NOAA, NTIS Accession No. PB301339/AS. 62 p.

Jackson, W.B. (Editor). 1979b. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1977-1978. Volume III: Chemical and Physical Investigations. NOAA, NTIS Accession No. PB80107899. 722 p.

Jackson, W.B. (Editor). 1979c. Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1977-1978. Volume II: Data management and biological investigations. NOAA Annual Report to DPA, Project Number EPA-IAG-D5-E693-EO. NOAA, NTIS Accession No. PB 80165970. 799 p.

Koons, C.B., C.D. McAuliffe and F.T. Weiss. 1976. Environmental aspects of produced waters from oil and gas extraction operations in offshore and coastal waters, p. 247-255. *In:* Proceedings 8th Annual Offshore Technology Conference, Houston, Texas. Vol 1. (1976).

LeCren, E.D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition of the perch (*Perca fluviatilis*). J. Animal Ecol. 20: 201-219.

Mackin, J.G. 1971. A study of the effect of oil field brine effluents on biotic communities in Texas estuaries. Proj. No. 735, Texas A&M Research Foundation, College Station, Texas. 72 p.

Mackin, J.G. 1973. A review of significant papers on effects of oil spills and oil field brine discharges on marine biotic communities. Proj. No. 737, Texas A&M Research Foundation, College Station, Texas. 86 p.

Middleditch, B.S. and D.L. West. 1980. Hydrocarbons, biocides and sulfur. Vol. 8. *In:* W.B. Jackson and P. Wilkens (eds.), Environmental assessment of an active oil field in the northwestern Gulf of Mexico. Chemical and Physical Investigations. NOAA Annual Report to EPA, Project Number EPA-IAG-D5-E693-EO. NOAA.

Pequegnat, W.E. and L.H. Pequegnat. 1968. Ecological aspects of marine fouling in the northeastern Gulf of Mexico. Technical Report to the Office of Naval Research. Proj.No. 286-6, Texas A&M Research Foundation, College Station, Texas. 80 p.

Tillery, J.B. 1980. Trace metals. Vol. 9. *In:* W.B. Jackson and P. Wilkens (eds.), Environmental assessment of an active oil field in the northwestern Gulf of Mexico. Chemical and Physical Investigations. NOAA Annual Report to EPA, Project No EPA-IAG-D5- E693-EO. NOAA.